ASME BPVC.VIII.1-2025

SECTION VIII

Rules for Construction of Pressure Vessels

2025 ASME Boiler and Pressure Vessel Code

An International Code

Division 1

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AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition July 1, 2025

VIII

RULES FOR CONSTRUCTION OF PRESSURE VESSELS

Division 1

ASME Boiler and Pressure Vessel Committee on Pressure Vessels

The American Society of Mechanical Engineers

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FOREWORD[*] (25)

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)
(b) Committee on Materials (II)
(c) Committee on Construction of Nuclear Facility Components (III)
(d) Committee on Heating Boilers (IV)
(e) Committee on Nondestructive Examination (V)
(f) Committee on Pressure Vessels (VIII)
(g) Committee on Welding, Brazing, and Fusing (IX)
(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
(i) Committee on Nuclear Inservice Inspection (XI)
(j) Committee on Transport Tanks (XII)
(k) Committee on Overpressure Protection (XIII)
(l) Technical Oversight Management Committee (TOMC)

Where reference is made to “the Committee” in this Foreword, each of these committees is included individually and collectively.

The Committee’s function is to establish rules of safety relating to pressure integrity. The rules govern the construction[**] of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. The Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity and, for nuclear items other than pressure-retaining components, structural integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of components addressed by the Code. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

The Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code

[*] The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

[**] *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of the Code. Requests for revisions, new rules, Code cases, or interpretations shall be addressed to the staff secretary in writing and shall give full particulars in order to receive consideration and action (see the Correspondence With the Committee page). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in the Code, the singular shall be interpreted as the plural, and vice versa.

The words "shall," "should," and "may" are used in the Code as follows:

– *Shall* is used to denote a requirement.
– *Should* is used to denote a recommendation.
– *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the ASME Single Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the ASME Single Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code." An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the ASME Single Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number to which the proposed case applies

(4) the editions of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements. Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Inquiry Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(25)**, placed next to the affected area. In addition, the term “impregnated” has been revised to “impervious” throughout Section VIII, Division 1.

Page	*Location*	*Change*
xxx	List of Sections	Title of Section XI, Division 1 revised
xxxi	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
xxxiv	Personnel	Updated
1	U-1	Subparagraph (b) revised
2	U-2	Subparagraphs (a), (a)(2), (b)(1), (b)(2), (b)(4), (e), and (h)(3) revised
5	U-6	Added
6	Table U-3	Updated
8	UG-1	Revised
8	UG-4	Subparagraphs (a) and (f) revised
9	UG-6	Subparagraphs (a) through (c) revised
10	UG-9	Revised in its entirety
10	UG-10	Revised in its entirety
13	UG-11(e)	Third cross-reference updated
14	UG-14	Revised in its entirety
15	Table UG-14-1	Added
16	Figure UG-14-1	Added
17	Figure UG-14-2	Added
15	UG-15	Revised in its entirety
15	UG-16	Revised in its entirety
18	UG-19	In subpara. (a), last sentence, “r” corrected by errata to “or”
19	UG-23	In subpara. (b)(2), Step 1 revised
21	UG-24	Revised in its entirety
22	UG-25	Subparagraph (a) revised
23	UG-28	*(1)* In definition of L in subpara. (b), item (c) revised *(2)* Subparagraph (f) revised
27	UG-29	In Note of subpara. (a), Step 7(b) , “6(b) and (b)” corrected by errata to “Step 6(b) and Step 7(b)”
34	UG-33	*(1)* In subpara. (b), definition of L_c revised *(2)* In subpara. (f), last sentence added
35	Figure UG-33.1	Sketches (a) and (b) revised
37	UG-34	Definition of W and subparas. (d)(4), (d)(10), and (d)(12) revised

Page	Location	Change
40	UG-35.2	Revised in its entirety
40	UG-35.3	Revised in its entirety
40	Table UG-35.2-1	Added
47	UG-39	In subpara. (b)(3), second sentence revised
48	Figure UG-39	Revised
57	Table UG-44-1	"Size Range" entries and Note (2) revised
59	UG-47	Subparagraph (b) revised
66	UG-75	Revised in its entirety
66	UG-76	Revised in its entirety
66	UG-77	Revised in its entirety
67	UG-78	Revised in its entirety
67	UG-79	Revised in its entirety
70	UG-84	*(1)* Revised in its entirety *(2)* Figures and tables redesignated
73	Figure UG-84.5-1	In former Figure UG-84.1, General Note (b) revised
74	Figure UG-84.5-1M	In former Figure UG-84.1M, General Note (b) revised
77	UG-85	Revised in its entirety
77	UG-90	Revised in its entirety
78	UG-91	Revised in its entirety
79	UG-92	Revised in its entirety
79	UG-93	Revised in its entirety
80	UG-94	Revised in its entirety
80	UG-95	Revised in its entirety
80	UG-96	Revised in its entirety
80	UG-97	Revised in its entirety
81	UG-99	Revised in its entirety
84	UG-100	Revised in its entirety
87	UG-101	Subparagraphs (a)(4)(-d) and (b) revised
92	UG-102	Revised in its entirety
93	UG-103	Revised in its entirety
93	UG-115	Revised in its entirety
93	UG-116	Subparagraph (a)(1)(-a) revised
95	UG-117	Subparagraph (g) revised
96	Figure UG-118	Revised
97	UG-119	Subparagraph (d) revised
97	UG-120	Subparagraphs (a)(1)(-b), (b)(1)(-c), (c)(1), (c)(1)(-a), and (c)(1)(-b) revised

Page	Location	Change
100	UG-151	Subparagraphs (a) and (c) revised
100	UG-152	Subparagraph (a) revised
100	UG-153	*(1)* Subparagraph (a) revised *(2)* In subpara. (a)(2), “Nonmandatory Appendix MM” corrected by errata to “Nonmandatory Appendix M”
101	UG-154	*(1)* Subparagraph (b)(3) revised *(2)* Subparagraph (c)(3) deleted *(3)* Subparagraphs (e)(3) and (e)(4) added
102	UG-155	Subparagraph (h) revised
104	UW-1	Revised
104	UW-2	Subparagraphs (a), (b)(1), (b)(4)(-a), (b)(4)(-b), and (d)(3) revised
105	UW-3	First paragraph and subparas. (c) and (d) revised
106	Figure UW-3	Category F added
107	UW-6	First paragraph revised
107	UW-8	Revised
109	UW-10	Revised
110	UW-12	First paragraph revised
112	Table UW-12	Type No. (9) added
111	UW-13	Subparagraphs (a), (f)(4), and (g)(1) revised
116	Figure UW-13.2	*(1)* Sketches (m) and (n) revised *(2)* Note (2) deleted and subsequent Note renumbered
120	UW-14	Revised in its entirety
120	UW-15	Revised in its entirety
136	UW-20.2	*(1)* Definition of P_o revised *(2)* Definitions of $S_{y,a}$ and $S_{y,t,a}$ added *(3)* Term “S_{yt}” corrected by errata to “$S_{y,t}$”
137	UW-20.3.4	In subpara. (b) nomenclature, terms “F” and “S” corrected by errata to “F_t” and “S_w,” respectively
140	UW-20.4.2	In subpara. (b), first two equations revised
141	Figure UW-20.3	Duplicate Figure UW-20.3 deleted by errata
144	Figure UW-21	Title corrected by errata
143	UW-26	*(1)* Subparagraphs (a), (b), and (d)(4)(-a) [formerly (d)(4)(-b)] revised *(2)* Subparagraph (d)(4)(-a) deleted and subsequent subparagraphs redesignated
144	UW-28	Subparagraph (b) revised
146	Table UW-33	Title added
146	UW-34	*(1)* Revised *(2)* Former Endnote 47 deleted and subsequent Endnotes renumbered
146	UW-35	Revised in its entirety

Page	*Location*	*Change*
147	UW-35-1	In-text table formerly in UW-35(e) designated and titled
146	UW-36	Deleted
146	UW-37	Subparagraph (f)(1) revised
148	UW-38	Second cross-reference updated
148	UW-40	Revised in its entirety
150	UW-46	Revised
150	UW-47	Revised
150	UW-48	Revised
150	UW-49	Revised
151	UW-50	Title and subpara. (a) revised
151	UW-51	Revised
151	UW-52	Subparagraph (b)(3) revised
153	UW-55	Revised in its entirety
154	UF-1	Second sentence revised
154	UF-5	Subparagraph (d) revised
154	UF-12	Second paragraph revised
156	UF-32	Subparagraph (d) added
157	UF-37	Subparagraph (b)(4) added
157	UF-38	Last sentence added
158	UF-43	First sentence revised
158	UF-52	Revised
158	UF-55	Subparagraph (a) revised
160	UB-1	Subparagraph (a) revised
161	UB-9	Revised
164	UB-30	Subparagraphs (a), (b), and (d)(4)(-b) revised
165	UB-40	Revised
165	UB-42	Revised
165	UB-43	Subparagraph (a) revised
166	UB-44	Subparagraph (a) revised
167	UCS-1	Revised
168	UCS-16	Revised
169	Table UCS-23	For SA-372, Type/Grade revised
170	UCS-56	Revised in its entirety
176	Table UCS-56-4	In Note (d)(1), cross-reference updated
181	Table UCS-56-11	In Note (b)(1), cross-reference updated
182	Table UCS-56-12	Former Table UCS-56.1 redesignated

Page	*Location*	*Change*
182	UCS-66	Subparagraphs (a)(1)(-a)(-1) and (a)(1)(-a)(-3) revised
183	Figure UCS-66	Table in Note (c) revised
186	Figure UCS-66M	Table in Note (c) revised
199	UCS-67	Revised in its entirety
199	Table UCS-67.2-1	Added
199	UCS-68	Revised in its entirety
200	UCS-75	Revised
201	UCS-85	Revised in its entirety
202	UCS-90	Revised
204	UNF-1	Revised
205	UNF-15	Subparagraph (b) revised
205	UNF-16	Revised
207	Table UNF-23.3	*(1)* SA-182, SA-213, SA-240, SA-312, SA-403, SA-479, SA-688, and SA-965 added *(2)* For SB-625, SB-649, and SB-677, UNS No. N08354 added
206	UNF-56	*(1)* In subpara. (c), Endnote 54 deleted and subsequent Endnotes renumbered *(2)* Subparagraph (d)(1) and (d)(3)(-a) revised
209	UNF-65	Revised in its entirety
209	UNF-75	Revised
210	UNF-78	Revised
210	UNF-90	Revised
214	UHA-1	Revised
215	UHA-20	Revised
216	Table UHA-23	SA-693 added
215	UHA-32	Subparagraph (d) revised
218	Table UHA-32-1	General Notes (a)(1) and (b) revised
219	Table UHA-32-2	*(1)* General Notes (a)(1), (b), and (c) [formerly (d)] revised *(2)* General Note (c) deleted and subsequent General Note redesignated
220	Table UHA-32-5	Second cross-reference in General Note (a) updated
221	UHA-40	Revised
222	UHA-42	Last sentence revised
222	UHA-50	Revised
222	UHA-51	Revised in its entirety
228	UHA-A-4	Cross-reference in subpara. (a)(5) updated
231	Table UCI-23	*(1)* "Class" column heading revised to "Class or Type" *(2)* SA-439 added
231	UCI-35	Revised

Page	*Location*	*Change*
232	UCI-78	Subparagraphs (a)(3) and (a)(4) revised
232	Table UCI-78.1	DN values added
232	Table UCI-78.2	DN values added
234	UCL-1	Last sentence revised
235	UCL-20	Subparagraph (a) revised
235	UCL-23	Last sentence revised
236	UCL-26	Revised
236	UCL-30	Revised
238	UCL-50	Revised
238	UCL-52	Cross-reference in subpara. (b) updated
239	UCD-3	In subpara. (b), Note revised
240	Table UCD-23	General Notes and Note (1) revised
240	UCD-78	Subparagraphs (a)(3) and (a)(4) revised
241	Table UCD-78.1	DN values added
241	Table UCD-78.2	DN values added
243	UHT-1	First sentence revised
244	UHT-16	Revised
245	UHT-18	Subparagraph (c)(2) revised
249	UHT-56	In subpara. (c), third cross-reference updated
250	UHT-75	Revised
253	UHT-86	Cross-reference updated
253	UHT-90	Revised
254	ULW-1	First sentence revised
265	ULW-18(d)	Revised
272	ULW-57	Subparagraph (a) revised
283	ULT-86	Second cross-reference updated
286	Subsection D	Added
286	Part UAS	Former Mandatory Appendix 48 redesignated
288	Part UCC	Former Mandatory Appendix 24 revised and redesignated
295	Part UDA	Former Mandatory Appendix 17 revised and redesignated
306	Part UEB	Former Mandatory Appendix 26 revised and redesignated
310	Form UEB-1	Former Form 26-1 redesignated and retitled
312	Form UEB-1M	Former Form 26-1M redesignated and retitled
314	Part UEJ	Former Mandatory Appendix 5 revised and redesignated
318	Part UGL	Former Mandatory Appendix 27 redesignated
320	Part UHX	Formerly in Subsection C, moved to Subsection D

Page	*Location*	*Change*
320	UHX-1	Subparagraph (a) revised and Table UHX-1.1 deleted
320	UHX-2	Revised
321	Table UHX-1-1	*(1)* Former Table UHX-1.2 revised and redesignated *(2)* Division 2 cross-reference for “Flexible shell element expansion joints” corrected by errata to 4.20
323	Part UIF	Former Mandatory Appendix 22 revised and redesignated
325	Part UIG	*(1)* Formerly in Subsection C, moved to Subsection D *(2)* In Nonmandatory Introduction, subparas. (b), (d), and (f) revised
325	UIG-1	Revised
326	UIG-3	*(1)* Definitions of *binder system, compound graphite material*, and *impregnated graphite material* added *(2)* Definitions of *certified materials, graphite cement, lot*, and *raw materials* revised *(3)* Definitions of *graphite compound* and *impervious materials* deleted
326	UIG-5	Subparagraph (b) revised
326	UIG-6	Subparagraph (b)(8) added and subpara. (c) revised
327	Table UIG-6-1	Revised in its entirety
327	UIG-7	Revised
327	UIG-8	Subparagraph (d) revised
327	UIG-23	Subparagraphs (c)(2) and (d) revised
327	UIG-27	Last sentence revised
328	UIG-28	Revised
328	UIG-34	Revised
336	Table UIG-34-1	For Operating Load Cases, shell side and tube side design pressures revised
337	Figure UIG-34-4	Sketch (a) revised
339	Table UIG-34-5	Last line revised
340	UIG-35	Added
341	Figure UIG-35-1	Added
341	Figure UIG-35-2	Added
340	UIG-36	Revised in its entirety
343	Figure UIG-36-2	Sketches (a) through (e), (g), and (h) revised
346	UIG-45	First sentence revised
347	UIG-75	Subparagraphs (b) and (d) revised
347	UIG-76	In subparas. (c) through (e), cross-references updated
348	Figure UIG-76-1	Revised
349	Figure UIG-76-1-M	Added
350	Figure UIG-76-2	Revised

Page	Location	Change
351	Figure UIG-76-2M	Added
353	Figure UIG-76-3M	Added
355	Figure UIG-76-4M	Added
357	Figure UIG-76-5M	Added
358	Figure UIG-76-6	Title revised
359	Figure UIG-76-6M	Added
360	UIG-77	Subparagraphs (d)(2) and (f) revised
360	UIG-78	Revised
360	UIG-79	Subparagraphs (b) and (e) revised
361	UIG-81	Revised in its entirety
361	UIG-84	Revised
362	Table UIG-84-1	Revised in its entirety
363	UIG-97	Revised in its entirety
363	UIG-101	Former Mandatory Appendix 36 revised and redesignated
364	UIG-102	Former Mandatory Appendix 37 revised and redesignated
365	UIG-103	Former Mandatory Appendix 38 revised and redesignated
367	UIG-104	Former Mandatory Appendix 39 revised and redesignated
368	UIG-105	Former Mandatory Appendix 40 revised and redesignated
371	UIG-116	Subparagraphs (e) and (f) added
371	UIG-120	Subparagraphs (c) and (d) added
372	UIG-121	Last sentence revised
373	Form CMQ	Revised in its entirety
380	Form CMQ-C	Added
386	Form CCQ	In table on first page, entry for UIG-6 revised
388	Form CPQ	*(1)* On first page, last cross-reference updated *(2)* In table on second page, "Block Joint Material" revised to "Block Joint"
391	Nonmandatory Appendix UIG-A	Cross-references updated throughout and UIG-A-3(d) revised
393	Nonmandatory Appendix UIG-B	Former Nonmandatory Appendix MM redesignated
394	Part UJK	Former Mandatory Appendix 19 redesignated
395	Part UJV	Former Mandatory Appendix 9 revised and redesignated
397	Part UNC	Former Mandatory Appendix 13 revised and redesignated
399	Part UPX	Former Mandatory Appendix 45 revised and redesignated
403	1-4	*(1)* Subparagraphs (a), (f)(1), and (f)(2) revised *(2)* In subpara. (b), definition of *S* revised
406	1-5	In subpara. (c), Note deleted

Page	Location	Change
409	1-6	*(1)* In subpara. (b), definition of M_o revised *(2)* Subparagraph (d)(3) revised
413	1-8	In subpara. (b)(3), Step 5, "$A = 2 - B/E_x$" corrected by errata to "$A = 2B/E_X$"
418	Mandatory Appendix 2	Revised in its entirety
422	3-2	*(1)* Definition of *acceptance by the Inspector, accepted by the Inspector* revised *(2)* Definition of *Certifying Engineer* deleted *(3)* Term *nominal pipe size (NPS)* revised to *nominal pipe size [NPS (DN)]* *(4)* Definition of *replacement or repair parts* added
433	Mandatory Appendix 5	Revised and redesignated as Part UEJ
434	6-2	Revised
436	7-1	Cross-reference updated
437	7-4	Subparagraph (d) revised
439	8-2	Revised
441	Mandatory Appendix 9	Revised and redesignated as Part UJV
442	10-1	Second paragraph revised
442	10-5	Subparagraphs (c)(1) and (c)(2) revised
443	10-9	Revised
443	10-11	Revised
443	10-13	Subparagraphs (a), (b)(6), (b)(7), (b)(8), and (b)(12) revised
444	10-15	Subparagraph (d) revised
446	Mandatory Appendix 13	Revised and redesignated Part UNC
447	Mandatory Appendix 14	Revised in its entirety
448	Mandatory Appendix 17	Revised and redesignated as Part UDA
450	Mandatory Appendix 19	Redesignated as Part UJK
453	Mandatory Appendix 22	Revised and redesignated as Part UIF
454	23-4	Subparagraphs (a)(3) and (b)(3) revised
456	Mandatory Appendix 24	Revised and redesignated as Part UCC
457	Mandatory Appendix 26	Revised and redesignated as Part UEB
458	Mandatory Appendix 27	Redesignated as Part UGL
461	Table 31-1	*(1)* Entries for Nominal Composition $2^1/_4$Cr–1Mo revised *(2)* General Note added
470	35-4	Subparagraph (c)(10) revised
473	Mandatory Appendix 36	Revised and redesignated as UIG-101
474	Mandatory Appendix 37	Revised and redesignated as UIG-102
475	Mandatory Appendix 38	Revised and redesignated as UIG-103
476	Mandatory Appendix 39	Revised and redesignated as UIG-104

Page	Location	Change
477	Mandatory Appendix 40	Revised and redesignated as UIG-105
478	41-2	Subparagraph (a) revised
478	41-5	*(1)* Definitions of C, G, h_r, S, and W revised *(2)* Definitions of S_a and W_{m1} deleted
480	41-7	Steps 1(b) and 8 revised
481	41-10.1	Subparagraph (b) and nomenclature in subpara. (d) revised
485	43-2	Subparagraph (a)(5) added
486	44-5	Subparagraph (i) revised
487	44-6.1	Subparagraphs (g)(2) and (g)(3) revised
489	Mandatory Appendix 45	Revised and redesignated as Part UPX
490	46-2	Revised
491	46-4	Cross-references updated and subparas. (c)(4) and (c)(5) revised
492	Mandatory Appendix 47	Revised in its entirety
493	Mandatory Appendix 48	Redesignated as Part UAS
496	E-3	First sentence revised
500	H-1	Revised
500	H-4.1	Second paragraph revised
504	L-1.2	First paragraph revised
504	L-1.4	Subparagraph (c) revised
505	Figure L-1.4-1	General Note (b) revised
508	Figure L-1.4-4	Revised
520	Form U-1	On third page, "Certificate of Shop Inspection" and "Certificate of Field Assembly Inspection" revised
523	Form U-1A	On second page, "Certificate of Shop/Field Inspection" revised
526	Form U-1P	On second page, "Certificate of Shop Inspection" and "Certificate of Field Assembly Inspection" revised
528	Form U-2	On third page, "Certificate of Shop/Field Inspection" revised
531	Form U-2A	On second page, "Certificate of Shop/Field Inspection" revised
541	Form U5-B	Added
542	Table W-3	*(1)* Column U-5B added *(2)* Instructions for items (33), (34), (40), (42), (53), (55), (58), (59), and (70) revised
548	Table W-3.1	Instructions for item (B) revised
550	Y-3	In subpara. (a), definitions of b, m, and y revised
556	Y-5.2	First sentence revised
563	Nonmandatory Appendix EE	Revised in its entirety
564	Nonmandatory Appendix FF	Deleted

Page	*Location*	*Change*
565	GG-2	Subparagraph (f) revised
577	Figure JJ-1.2-1	Cross-references updated
578	Figure JJ-1.2-2	Cross-references updated
579	Figure JJ-1.2-3	Cross-references updated
580	Figure JJ-1.2-4	Cross-references updated
581	Figure JJ-1.2-5	Cross-references updated
583	Form U-DR-1	On second page, Category F added
585	Form U-DR-2	On second page, Category F added
588	Nonmandatory Appendix LL	Deleted
589	Nonmandatory Appendix MM	Redesignated as UIG-B
590	NN-1	Revised
590	NN-2	Subparagraphs (a)(2) through (a)(4) and (b)(1) revised
591	NN-5	Title revised
592	NN-6	Revised
593	Table NN-6-1	Revised
594	Table NN-6-2	Revised
594	Table NN-6-3	First row revised
594	Table NN-6-4	Last row revised
595	Table NN-6-5	Title revised and last row added
596	Table NN-6-6	Title and last row revised
596	Table NN-6-7	Title and entry for “Prior notification of weld repair” revised
597	Table NN-6-8	Revised
597	Table NN-6-9	Entry for “Painting before pressure testing” revised
598	Table NN-6-11	Deleted

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

INTRODUCTION

(25) U-1 SCOPE

(a) See below.

(1) The Foreword provides the basis for the rules described in this Division.

(2) For the scope of this Division, pressure vessels are containers for the containment of pressure, either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or any combination thereof.

(3) This Division contains mandatory requirements, specific prohibitions, and nonmandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. The Code does not address all aspects of these activities, and those aspects which are not specifically addressed should not be considered prohibited. Engineering judgment must be consistent with the philosophy of this Division, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of this Division.

(b) This Division is divided into four Subsections, Mandatory Appendices, and Nonmandatory Appendices.

(1) Subsection A covers general requirements applicable to all pressure vessels.

(2) Subsection B covers specific requirements applicable to the various methods used in the fabrication of pressure vessels.

(3) Subsection C covers specific requirements applicable to the several classes of materials used in pressure vessel construction.

(4) Subsection D covers requirements applicable to specific types of pressure vessels and components.

(5) The Mandatory Appendices address specific subjects not covered elsewhere in this Division, and their requirements are mandatory when the subject covered is included in construction under this Division.

(6) The Nonmandatory Appendices provide information and suggested good practices.

(c) See below.

(1) The scope of this Division has been established to identify the components and parameters considered in formulating the rules given in this Division. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Division of the Code for vessels or components not considered to be within its scope. These laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than those given here.

(2) Based on the Committee's consideration, the following classes of vessels are not included in the scope of this Division; however, any pressure vessel which meets all the applicable requirements of this Division may be stamped with the Certification Mark with the U Designator:

(-a) those within the scope of other Sections;

(-b) fired process tubular heaters;

(-c) pressure containers which are integral parts or components of rotating or reciprocating mechanical devices, such as pumps, compressors, turbines, generators, engines, and hydraulic or pneumatic cylinders where the primary design considerations and/or stresses are derived from the functional requirements of the device;

(-d) structures whose primary function is the transport of fluids from one location to another within a system of which it is an integral part, that is, piping systems;

(-e) piping components, such as pipe, flanges, bolting, gaskets, valves, expansion joints, and fittings, and the pressure-containing parts of other components, such as strainers and devices which serve such purposes as mixing, separating, snubbing, distributing, and metering or controlling flow, provided that pressure-containing parts of such components are generally recognized as piping components or accessories;

(-f) a vessel for containing water[1] under pressure, including those containing air the compression of which serves only as a cushion, when none of the following limitations are exceeded:

(-1) a design pressure of 300 psi (2 MPa);

(-2) a design temperature of 210°F (99°C);

(-g) a hot water supply storage tank heated by steam or any other indirect means when none of the following limitations is exceeded:

(-1) a heat input of 200,000 Btu/hr (58.6 kW);

(-2) a water temperature of 210°F (99°C);

(-3) a nominal water containing capacity of 120 gal (450 L);

(-h) vessels not exceeding the design pressure (see Mandatory Appendix 3, 3-2), at the top of the vessel, limitations below, with no limitation on size [see UG-28(f) and UJV-1(d)]:

(-1) vessels having an internal or external pressure not exceeding 15 psi (100 kPa);

(-2) combination units having an internal or external pressure in each chamber not exceeding 15 psi (100 kPa) and differential pressure on the common elements not exceeding 15 psi (100 kPa) [see UG-19(a)];

(-i) vessels having an inside diameter, width, height, or cross section diagonal not exceeding 6 in. (152 mm), with no limitation on length of vessel or pressure;

(-j) pressure vessels for human occupancy.[2]

(d) The rules of this Division have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures not exceeding 3,000 psi (20 MPa). For pressures above 3,000 psi (20 MPa), deviations from and additions to these rules usually are necessary to meet the requirements of design principles and construction practices for these higher pressures. Only in the event that after having applied these additional design principles and construction practices the vessel still complies with all of the requirements of this Division may it be stamped with the applicable Certification Mark with the Designator.

(e) In relation to the geometry of pressure-containing parts, the scope of this Division shall include the following:

(1) where external piping; other pressure vessels including heat exchangers; or mechanical devices, such as pumps, mixers, or compressors, are to be connected to the vessel:

(-a) the welding end connection for the first circumferential joint for welded connections [see UW-13(i)];

(-b) the first threaded joint for screwed connections;

(-c) the face of the first flange for bolted, flanged connections;

(-d) the first sealing surface for proprietary connections or fittings;

(2) where nonpressure parts are welded directly to either the internal or external pressure-retaining surface of a pressure vessel, this scope shall include the design, fabrication, testing, and material requirements established for non-pressure-part attachments by the applicable paragraphs of this Division;[3]

(3) pressure-retaining covers for vessel openings, such as manhole or handhole covers, and bolted covers with their attaching bolting and nuts;

(4) the first sealing surface for proprietary fittings or components for which rules are not provided by this Division, such as gages, instruments, and nonmetallic components.

(f) The scope of the Division includes requirements for overpressure protection in UG-150 through UG-156.

(g) Vessels That Generate Steam

(1) Unfired steam boilers shall be constructed in accordance with the rules of Section I or this Division [see UG-120(f), UG-150(d), and UW-2(c)].

(2) The following pressure vessels in which steam is generated shall not be considered as unfired steam boilers, and shall be constructed in accordance with the rules of this Division:

(-a) vessels known as evaporators or heat exchangers;

(-b) vessels in which steam is generated by the use of heat resulting from operation of a processing system containing a number of pressure vessels such as used in the manufacture of chemical and petroleum products;

(-c) vessels in which steam is generated but not withdrawn for external use.

(h) Pressure vessels or parts subject to direct firing from the combustion of fuel (solid, liquid, or gaseous), which are not within the scope of Sections I, III, or IV may be constructed in accordance with the rules of this Division [see UW-2(d)].

(i) Gas fired jacketed steam kettles with jacket operating pressures not exceeding 50 psi (345 kPa) may be constructed in accordance with the rules of this Division (see Part UJK).

(j) Pressure vessels exclusive of those covered in (c), (g), (h), and (i) that are not required by the rules of this Division to be fully radiographed, that are not provided with quick-actuating or quick-opening closures (see UG-35.2 and UG-35.3, respectively), and that do not exceed the following volume and pressure limits may be exempted from inspection by Inspectors, as defined in UG-91, provided that they comply in all other respects with the requirements of this Division:

(1) 5 ft^3 (0.14 m^3) in volume and 250 psi (1.7 MPa) design pressure; or

(2) 3 ft^3 (0.08 m^3) in volume and 350 psi (2.4 MPa) design pressure;

(3) $1^1/_2$ ft^3 (0.04 m^3) in volume and 600 psi (4.1 MPa) design pressure.

In an assembly of vessels, the limitations in (1) through (3) above apply to each vessel and not the assembly as a whole. Straight line interpolation for intermediate volumes and design pressures is permitted. Vessels fabricated in accordance with this rule shall be marked with the "UM" Designator in Figure UG-116, sketch (b) and with the data required in UG-116. Certificates of Compliance shall satisfy the requirements of UG-120(a).

U-2 GENERAL (25)

(a) The user or the user's designated agent (see Nonmandatory Appendix NN) shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration.

(1) Such consideration shall include but shall not be limited to the following:

(-a) all loadings listed in UG-22.

(-b) the need for corrosion allowances;

(-c) damage mechanisms and service restrictions associated with the service fluid at design conditions. Informative and nonmandatory guidance regarding metallurgical phenomena is provided in Section II, Part D, Nonmandatory Appendix A, API RP 571, and WRC Bulletins 488, 489, and 490.

(-d) the need for postweld heat treatment beyond the requirements of this Division and dependent on service conditions;

(-e) for pressure vessels in which steam is generated, or water is heated [see U-1(g) and U-1(h)], the need for piping, valves, instruments, and fittings to perform the functions covered by Section I, PG-59 through PG-61.

(-f) the degree of nondestructive examination(s) and the selection of applicable acceptance standards when such examinations are beyond the requirements of this Division.

(2) *User's Design Requirements Form*

(-a) A User's Design Requirements Form, or other document with equivalent information, shall be provided when any of the following conditions is a design requirement:

(-1) superimposed static reactions [see UG-22(c)]

(-2) cyclic or dynamic reactions [see UG-22(e)]

(-3) loadings due to wind, snow, or seismic reactions [see UG-22(f)]

(-4) impact reactions [see UG-22(g)]

(-5) temperature effects [see UG-22(h)]

(-6) abnormal pressures [see UG-22(i)]

(-b) A User's Design Requirements Form or other document with equivalent information shall be provided when overpressure protection by system design in accordance with Section XIII, Part 13 has been chosen.

(-c) A User's Design Requirements Form or other document with equivalent information shall be provided when the user of an existing Code pressure vessel is specifying replacement or repair parts to be built by a parts Manufacturer that performs no design function. The user shall identify on the form the parts as "User-Specified Parts."

(-d) Sample User's Design Requirements Forms and guidance on their preparation are found in Nonmandatory Appendix KK. This sample form might not be applicable to all pressure vessels that may be constructed in accordance with this Division. The user is cautioned that input from the Manufacturer may be necessary for completion of this form.

(b) *Responsibilities*[4]

(1) The Manufacturer is responsible for the structural and pressure-retaining integrity of a vessel or part thereof, as established by conformance with the requirements of the rules of this Division and any additional requirements specified in the User's Design Requirements Form when provided. The Manufacturer's Data Report shall include the design requirements of (a)(2)(-a) and and (a)(2)(-b)when specified.

(2) The Manufacturer of any vessel or part to be marked with the Certification Mark has the responsibility of complying with all of the applicable requirements of this Division and, through proper certification, of assuring that all work done by others also complies. The vessel Manufacturer or, when applicable, the part Manufacturer is responsible for the preparation and accuracy of design calculations to show compliance with the rules of this Division, and the vessel or part Manufacturer's signature on the Manufacturer's Data Report Form shall be considered as certification that this has been done. The vessel or part Manufacturer shall have available for the Inspector's review the applicable design calculations and, when provided, the User's Design Requirements Form. See Mandatory Appendix 10, 10-5 and 10-15(d).

(3) The Manufacturer has the responsibility of ensuring all personnel performing design activities are qualified in the applicable area(s) of design. See Mandatory Appendix 10 and Mandatory Appendix 47.

(4) The Manufacturer has the responsibility to report methods of design used that are not covered by the rules of this Division [see (g)], and shall be described in the "Remarks" of the Manufacturer's Data Report.

(5) Some types of work, such as forming, nondestructive examination, and heat treating, may be performed by others (for welding, see UW-26 and UW-31). It is the vessel or part Manufacturer's responsibility to ensure that all work so performed complies with all the applicable requirements of this Division. After ensuring Code compliance, the vessel or part may be stamped with the Certification Mark and Designator by the appropriate Certificate holder after acceptance by the Inspector.

(c) A vessel may be designed and constructed using any combination of the methods of fabrication and the classes of materials covered by this Division, provided the rules applying to each method and material are complied with and the vessel is marked as required by UG-116.

(d) When the strength of any part cannot be computed with a satisfactory assurance of safety, the rules provide procedures for establishing its maximum allowable working pressure.

(e) It is the duty of the Inspector to make all of the inspections specified by the rules of this Division, and to monitor the quality control and the examinations made by the Manufacturer. The Inspector shall make such other inspections deemed necessary by the Inspector to permit certification that the vessel has been designed and constructed in accordance with the minimum requirements of this Division. The Inspector has the duty of verifying that the applicable design calculations have been made and are on file at Manufacturer's plant at the time the Data Report is signed. Any questions concerning the calculations raised by the Inspector must be resolved. See UG-90.3.

NOTE: The term "applicable design calculations" means that all pressure-retaining components covered by the Certification Mark stamping are supported by calculations and/or proof tests that comply with the requirements of this Division. The method of verifying that applicable design calculations have been made will vary with the individual Inspector and depend largely on the Manufacturer's procedures for producing the design calculations and any subsequent quality checks performed by the Manufacturer.

(f) The rules of this Division shall serve as the basis for the Inspector to:

(1) perform the required duties;

(2) authorize the application of the Certification Mark;

(3) sign the Certificate of Shop (or Field Assembly) Inspection.

(g) This Division of Section VIII does not contain rules to cover all details of construction. Where complete details of construction are not given, the Manufacturer, subject to the acceptance of the Authorized Inspector, shall provide the appropriate details to be used.

(1) Where design rules do not exist in this Division, one of the following three methods shall be used:

(-a) Mandatory Appendix 46.

(-b) proof test in accordance with UG-101.

(-c) other recognized and generally accepted methods, such as those found in other ASME, EN, ISO, national, and industry standards or codes. This option shall provide details of design consistent with the allowable stress criteria provided in UG-23.

(2) The provisions of this paragraph shall not be used to justify the use of materials, joining processes (fabrication), examination, inspection, testing, certification, and overpressure protection methods other than those allowed by this Division.

(h) Field assembly of vessels constructed to this Division may be performed as follows.

(1) The Manufacturer of the vessel completes the vessel in the field; completes the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P within Nonmandatory Appendix W, and stamps the vessel.

(2) The Manufacturer of parts of a vessel to be completed in the field by some other party stamps these parts in accordance with Code rules and supplies the Manufacturer's Partial Data Report Form U-2 or Form U-2A to the other party. The other party, who must hold a valid U Certificate of Authorization, makes the final assembly, required NDE, and final pressure test; completes the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P, and stamps the vessel.

(3) The field portion of the work is completed by a holder of a valid U Certificate of Authorization other than the vessel Manufacturer. The Certificate Holder performing the field work is required to supply the Manufacturer's Partial Data Report Form U-2 or Form U-2A covering the organization's portion of the work completed (including data on the pressure test if conducted by the Certificate Holder performing the field work) to the Manufacturer responsible for the Code vessel. The vessel Manufacturer applies the Certification Mark with the U Designator in the presence of a representative from the Inspection Agency and completes the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P with the Inspector.

In all three alternatives, the party completing and signing the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P assumes full Code responsibility for the vessel. In all three cases, each Manufacturer's Quality Control System shall describe the controls to assure compliance for each Certificate Holder.

(i) For some design analyses, both a chart or curve and a equation or tabular data are given. Use of the equation or tabular data may result in answers which are slightly different from the values obtained from the chart or curve. However, the difference, if any, is within practical accuracy and either method is acceptable.

(j) The Manufacturer of the completed vessel shall establish the construction requirements for subcontracted parts [see Mandatory Appendix 43, 43-2(a)(2)] requiring inspection under this Division. The Manufacturer shall give consideration to the compatibility of the parts with the completed vessel. Such consideration shall include, but not be limited to, the following:

(1) the design requirements established by the user or the user's designated agent [see (a)]

(2) the Certificate Holder responsible for design [see UG-120(c)(1)(-b)]

(3) the need for pressure testing by the Manufacturer of the part, including the required test pressure

(4) impact testing requirements for materials and/or welding procedure qualifications

(5) compliance with special requirements for vessels intended for special services [see UG-120(d)]

(6) the need for preheat or postweld heat treatment

(7) the extent and method of nondestructive examination (see UW-12)

(8) the units of measurement (see U-4)

(9) the mandated Edition of the Code to be used for construction (see Mandatory Appendix 43)

U-3 STANDARDS REFERENCED BY THIS DIVISION

(a) Throughout this Division references are made to various standards, such as ASME standards, which cover pressure–temperature rating, dimensional, or procedural standards for pressure vessel parts. These standards, with the year of the acceptable edition, are listed in Table U-3.

(b) Rules for the use of these standards are stated elsewhere in this Division.

U-4 UNITS OF MEASUREMENT[5]

(a) U.S. Customary, SI, or any local customary units may be used to demonstrate compliance with requirements of this edition related to materials, fabrication, examination, inspection, testing, certification, and overpressure protection.

(b) A single system of units shall be used for all aspects of design except where otherwise permitted by this Division. When components are manufactured at different locations where local customary units are different than those used for the general design, the local units may be used for the design and documentation of that component, subject to the limitations given in (c). Similarly, for proprietary components or those uniquely associated with a system of units different than that used for the general design, the alternate units may be used for the design and documentation of that component, subject to the limitations given in (c).

(c) For any single equation, all variables shall be expressed in a single system of units. Calculations using any material data published in this Division or Section II, Part D (e.g., allowable stresses, physical properties, external pressure design factor B) shall be carried out in one of the standard units given in Table U-4-1. When separate equations are provided for U.S. Customary and SI units, those equations must be executed using variables in the units associated with the specific equation. Data expressed in other units shall be converted to U.S. Customary or SI units for use in these equations. The result obtained from execution of these equations or any other calculations carried out in either U.S. Customary or SI units may be converted to other units.

(d) Production, measurement and test equipment, drawings, Welding Procedure Specifications, welding procedure and performance qualifications, and other fabrication documents may be in U.S. Customary, SI, or local customary units in accordance with the fabricator's practice. When values shown in calculations and analysis, fabrication documents, or measurement and test equipment are in different units, any conversions necessary for verification of Code compliance and to ensure that dimensional consistency is maintained, shall be in accordance with the following:

(1) Conversion factors shall be accurate to at least four significant figures.

(2) The results of conversions of units shall be expressed to a minimum of three significant figures.

(e) Conversion of units, using the precision specified above, shall be performed to assure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in Nonmandatory Appendix GG, Guidance for the Use of U.S. Customary and SI Units in the ASME Boiler and Pressure Vessel Code. Whenever local customary units are used, the Manufacturer shall provide the source of the conversion factors which shall be subject to verification and acceptance by the Authorized Inspector or Certified Individual.

(f) Dimensions shown in the text, tables, and figures, whether given as decimals or fractions, may be taken as decimals or fractions and do not imply any manufacturing precision or tolerance on the dimensions.

(g) Material that has been manufactured and certified to either the U.S. Customary or SI material specification (e.g., SA-516M) may be used regardless of the unit system used in design. Standard fittings (e.g., flanges, elbows, etc.) that have been certified to either U.S. Customary units or SI units may be used regardless of the units system used in design.

(h) All entries on a Manufacturer's Data Report and data for Code-required nameplate marking shall be in units consistent with the fabrication drawings for the component using U.S. Customary, SI, or local customary units. Units (either primary or alternative) may be shown parenthetically. Users of this Code are cautioned that the receiving jurisdiction should be contacted to ensure the units are acceptable.

U-5 TOLERANCES

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

U-6 CROSS-REFERENCES TO SECTION VIII, DIVISION 2 (25)

In some instances, this Division references Section VIII, Division 2 for design rules. If a cross-referenced Division 2 requirement then refers to another Division 2 element (e.g., a paragraph, figure, or table), the designer using this Division shall use the applicable element of this Division. Refer to the relevant tables located at the beginning of each Part or Appendix that references Division 2 design rules.

For example, see Part UEJ, Table UEJ-1-2, which lists the Division 1 elements that are used in lieu of Division 2 elements referenced in the Division 2 design rules.

(25)

Table U-3
Year of Acceptable Edition of Referenced Standards in This Division

Title	Number	Year
Pipe Threads, General Purpose (Inch)	ANSI/ASME B1.20.1	Latest edition
Marking and Labeling Systems	ANSI/UL-969	Latest edition
Seat Tightness of Pressure Relief Valves	API Std. 527	2020
Minimum Design Loads and Associated Criteria for Buildings and Other Structures	ASCE/SEI 7	2022
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1	Latest edition
Gray Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, and 250	ASME B16.1	2020
Pipe Flanges and Flanged Fittings, NPS $^1/_2$ Through NPS 24 Metric/Inch Standard	ASME B16.5	2025 [Note (1)], [Note (4)]
Factory-Made Wrought Buttwelding Fittings	ASME B16.9	Latest edition
Forged Fittings, Socket-Welding and Threaded	ASME B16.11	Latest edition
Cast Copper Alloy Threaded Fittings, Classes 125 and 250	ASME B16.15	Latest edition
Metallic Gaskets for Pipe Flanges	ASME B16.20	Latest edition
Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves, Classes 150, 300, 600, 900, 1500, and 2500	ASME B16.24	2021
Ductile Iron Pipe Flanges and Flanged Fittings, Classes 150 and 300	ASME B16.42	2021
Large Diameter Steel Flanges, NPS 26 Through NPS 60 Metric/Inch Standard	ASME B16.47	2025 [Note (4)]
Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)	ASME B18.2.2	Latest edition
Welded and Seamless Wrought Steel Pipe	ASME B36.10M	Latest edition
Conformity Assessment Requirements	ASME CA-1	Latest edition
Pressure Boundary Bolted Flange Joint Assembly	ASME PCC-1	2022
Repair of Pressure Equipment and Piping	ASME PCC-2	2022
Standard Test Method for Measurement of Fracture Toughness	ASTM E1820	2024
Section VIII - Division 1 Example Problem Manual	ASME PTB-4	Latest edition
Criteria for Shell-and-Tube Heat Exchangers According to Part UHX of ASME Section VIII-Division 1	ASME PTB-7	2014
Safety Standard for Pressure Vessels for Human Occupancy	ASME PVHO-1	2016
Qualifications for Authorized Inspection	ASME QAI-1	Latest edition [Note (2)]
Standard Practice for Quantitative Measurement and Reporting of Hypoeutectoid Carbon and Low-Alloy Steel Phase Transformations	ASTM A1033	Latest edition
Standard Test Method for Flash Point by Tag Closed Tester	ASTM D56	Latest edition
Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester	ASTM D93	Latest edition
Standard Guide for Preparation of Metallographic Specimens	ASTM E3	2017
Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings	ASTM E125	1963 (R2023) [Note (3)]
Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness	ASTM E140	Latest edition
Standard Reference Radiographs for Heavy-Walled [2 to 4$^1/_2$ in. (50.8 to 114 mm)] Steel Castings	ASTM E186	2020
Standard Test Method for Conducting Drop-Weight Test to Determine Nil– Ductility Transition Temperature of Ferritic Steels	ASTM E208	Latest edition
Standard Reference Radiographs for Heavy-Walled [4$^1/_2$ to 12 in. (114 to 305 mm)] Steel Castings	ASTM E280	2021
Standard Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness	ASTM E446	2020
Metallic Materials — Charpy Pendulum Impact Test Part 1: Test Method	ISO 148-1	Latest edition
Metallic Materials — Charpy Pendulum Impact Test Part 2: Verification of Testing Machines	ISO 148-2	Latest edition
Metallic Materials — Charpy Pendulum Impact Test Part 3: Preparation and Characterization of Charpy V-Notch Test Pieces for Indirect Verification of Pendulum Impact Machines	ISO 148-3	Latest edition
Metric Standards		
Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal	AWS A4.2M	Latest edition
Metric Screw Thread — M Profile	ASME B1.13M	Latest edition

Table U-3
Year of Acceptable Edition of Referenced Standards in This Division (Cont'd)

Title	Number	Year
Metric Screw Thread — MJ Profile	ASME B1.21M	Latest edition
Metric Heavy Hex Screws	ASME B18.2.3.3M	Latest edition
Metric Fasteners for Use in Structural Applications	ASME B18.2.6M	Latest edition
Standard Test Method for Compressive Strength of Carbon and Graphite	ASTM C695	2021
Standard Practices for Force Verification of Testing Machines	ASTM E4	2021
Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods	ASTM E177	2020
Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method	ASTM E691	2023

NOTES:
(1) See UG-11(a)(2).
(2) See UG-91 and UG-117(a).
(3) R — Reaffirmed.
(4) The use of a flange or flanged fitting that relies on and meets the requirements of a B16 Case is not permitted.

Table U-4-1
Standard Units for Use in Equations

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches (in.^{2})	square millimeters (mm^2)
Volume	cubic inches (in.^{3})	cubic millimeters (mm^3)
Section modulus	cubic inches (in.^{3})	cubic millimeters (mm^3)
Moment of inertia of section	inches^4 (in.^{4})	millimeters^4 (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (°R)	kelvin (K)
Fracture toughness	ksi square root inches (ksi$\sqrt{\text{in.}}$)	MPa square root meters (MPa$\sqrt{\text{m}}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

SUBSECTION A
GENERAL REQUIREMENTS

PART UG
GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION AND ALL MATERIALS

(25) UG-1 SCOPE

The requirements of Part UG are applicable to all pressure vessels and vessel parts and shall be used in conjunction with the specific requirements in Subsections B, C, and D and the Mandatory Appendices that pertain to the method of fabrication and the material used.

MATERIALS

(25) UG-4 GENERAL

(a) Material subject to stress due to pressure shall conform to one of the specifications given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, including all applicable notes in the tables, and shall be limited to those that are permitted in the applicable Part of Subsection C, except as otherwise permitted in UG-9; UG-10; UG-11; UG-15; Part UCS; Subsection D, Part UIG; and the Mandatory Appendices. Material may be identified as meeting more than one material specification and/or grade, provided the material meets all requirements of the identified material specification(s) and/or grade(s) [see UG-23(a)].

(b) Material for nonpressure parts, such as skirts, supports, baffles, lugs, clips, and extended heat transfer surfaces, need not conform to the specifications for the material to which they are attached or to a material specification permitted in this Division, but if attached to the vessel by welding shall be of weldable quality [see UW-5(b)]. The allowable stress values for material not identified in accordance with UG-93 shall not exceed 80% of the maximum allowable stress value permitted for similar material in Subsection C.

(c) Material covered by specifications in Section II is not restricted as to the method of production unless so stated in the specification, and so long as the product complies with the requirements of the specification. (See UG-85.)

(d) Materials other than those allowed by the rules of this Division shall not be used. Data for new materials shall be submitted to and approved by the ASME Boiler and Pressure Vessel Committee on Materials in accordance with Section II, Part D, Mandatory Appendix 5.

(e) Materials outside the limits of size and/or thickness given in the title or scope clause of the specifications given in Section II, and permitted by the applicable Part of Subsection C, may be used if the material is in compliance with the other requirements of the specification,[6] and no size or thickness limitation is given in the stress tables. In those specifications in which chemical composition or mechanical properties vary with size or thickness, materials outside the range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

(f) It is recommended that the user or the user's designated agent ensure that materials used for the construction of the vessels will be suitable for the intended service with respect to retention of satisfactory mechanical properties, and resistance to corrosion, erosion, oxidation, and other deterioration during their intended service life. See also informative and nonmandatory guidance regarding metallurgical phenomena in Section II, Part D, Nonmandatory Appendix A.

(g) When specifications, grades, classes, and types are referenced, and the material specification in Section II, Part A or Part B is a dual-unit specification (e.g., SA-516/SA-516M), the design values and rules shall be applicable to either the U.S. Customary version of the material specification or the SI unit version of the material specification. For example, when SA-516M Grade 485 is used in construction, the design values listed for its equivalent, SA-516 Grade 70, in either the U.S. Customary or metric Section II, Part D (as appropriate) shall be used.

(h) When the rules of this Division require the use of material physical properties, these properties shall be taken from the applicable tables in Section II, Part D,

Subpart 2. If the applicable tables in Section II, Part D, Subpart 2 do not contain these properties for a permitted material or do not list them within the required temperature range, the Manufacturer may use other authoritative sources for the needed information. The Manufacturer's Data Report shall note under "Remarks" the property values obtained and their source.

NOTE: If material physical properties are not listed, the Manufacturer is encouraged to bring the information to the attention of the ASME Committee on Materials (BPV Section II) so that the data can be added in Section II, Part D, Subpart 2.

UG-5 PLATE[7]

Plate used in the construction of pressure parts of pressure vessels shall conform to one of the specifications in Section II for which allowable stress values are given in the tables referenced in UG-23, except as otherwise provided in UG-4, UG-10, UG-11, and UG-15.

(25) ## UG-6 FORGINGS

(a) Specifications and maximum allowable stress values for acceptable forging materials are given in the tables referenced in UG-23. (See Part UF for forged vessels.)

(b) Bar [as defined in UG-14(a)] that is forged independent of the material specification to which it is certified may be used only within the limitations of UG-14.

(c) Forgings certified to SA-105, SA-181, SA-182, SA-350, SA-403, and SA-420 may be used as tubesheets and hollow cylindrical forgings for pressure vessel shells that otherwise meet all the rules of this Division, provided the following additional requirements are met:

(1) Forgings certified to SA-105 or SA-181 shall be subject to one of the austenitizing heat treatments permitted by these specifications.

(2) One tension test specimen shall be taken from each forging weighing more than 5,000 lb (2 250 kg). The largest obtainable tension test specimen as specified by the test methods referenced in the applicable specification shall be used. Except for upset-disk forgings, the longitudinal axis of the test specimen shall be taken parallel to the direction of major working of the forging. For upset-disk forgings, the longitudinal axis of the test specimen shall be taken in the tangential direction. When agreed to by the Manufacturer, and when not prohibited by the material specification, test specimens may be machined from specially forged test blocks meeting the provisions provided in SA-266 or other similar specifications for large forgings.

(3) For quenched and tempered forgings weighing more than 10,000 lb (4 500 kg) at the time of heat treatment, two tension test specimens shall be taken from each forging. These shall be offset 180 deg from each other, except that if the length of the forging, excluding test prolongations, exceeds 12 ft (3.7 m), then one specimen shall be taken from each end of the forging.

UG-7 CASTINGS

Cast material may be used in the construction of pressure vessels and vessel parts. Specifications and maximum allowable stress values for acceptable casting materials are given in the tables referenced in UG-23. These allowable stress values shall be multiplied by the applicable casting quality factor given in UG-24 for all materials except cast iron.

UG-8 PIPE AND TUBES

(a) Pipe and tubes of seamless or welded[8] construction conforming to one of the specifications given in Section II may be used for shells and other parts of pressure vessels. Allowable stress values for the materials used in pipe and tubes are given in the tables referenced in UG-23.

(b) Integrally finned tubes may be made from tubes that conform in every respect with one of the specifications given in Section II. The requirements of (1), (2), (3), and (5) do not apply to tubes produced in accordance with a Section II integrally-finned material specification. These tubes may be used under the following conditions:

(1) The tubes, after finning, shall have a temper or condition that conforms to one of those provided in the governing specifications, or, when specified, they may be furnished in the "as-fabricated condition" where the finned portions of the tube are in the cold worked temper (as-finned) resulting from the finning operation, and the unfinned portions in the temper of the tube prior to finning.

(2) The maximum allowable stress value for the finned tube shall be that given in the tables referenced in UG-23 for the tube before finning except as permitted in (3) below.

(3) The maximum allowable stress value for a temper or condition that has a higher stress value than that of the tube before finning may be used, provided that qualifying mechanical property tests demonstrate that such a temper or condition is obtained and conforms to one of those provided in the governing specifications in Section II, and provided that allowable stress values have been established in the tables referenced in UG-23 for the tube material used. The qualifying mechanical property tests shall be made on specimens of finned tube from which the fins have been removed by machining. The frequency of tests shall be as required in the unfinned tube specification.

(4) The maximum allowable internal or external working pressure of the tube shall be based on the root diameter and the minimum wall of the finned section, or the outside diameter and wall of the unfinned section together with appropriate stress values, whichever results in the lower maximum allowable working pressure. Alternatively, the maximum allowable external pressure for tubes with integral fins may be established under the rules of Mandatory Appendix 23.

(5) In addition to the tests required by the governing specifications, each tube after finning shall be subjected to a pneumatic test or a hydrostatic test as indicated below. UG-90.3(a)(10) requirement for a visual inspection by the Inspector does not apply to either of these tests.

(-a) an internal pneumatic test of not less than 250 psi (1.7 MPa) for 5 sec without evidence of leakage. The test method shall permit easy visual detection of any leakage such as immersion of the tube under water or a pressure differential method.[9]

(-b) an individual tube hydrostatic test in accordance with UG-99 that permits complete examination of the tube for leakage.

(25) UG-9 WELDING MATERIALS

UG-9.1 Production Welding Materials. Welding materials used for production shall meet the requirements of this Division, Section IX, and the applicable qualified Welding Procedure Specification.

UG-9.2 Identification of Welding Materials. The vessel or part Manufacturer may accept one or more of the following for identification of welding materials:

(a) the marking or tagging of the welding material, containers, or packages as required by the Section II, Part C specification to which the material conforms

(b) the marking or tagging of the materials in the Welding Procedure Specification if the material does not conform to a Section II, Part C specification

(c) the Test Report

(d) the Certificate of Compliance

(25) UG-10 RECERTIFICATION OF MATERIAL TO A SPECIFICATION PERMITTED BY THIS DIVISION

UG-10.1 Recertification Procedural Requirements.

(a) Only a Certificate Holder (vessel or part Manufacturer) shall recertify material.

(b) The Certificate Holder shall only recertify a material to a specification permitted by this Division that is any of the following (see also Mandatory Appendix 43):

(1) an ASME material specification published in the current Edition of Section II, Part A or Part B

(2) a material specification otherwise explicitly permitted by the current Edition of Section II, Part A, Mandatory Appendix II or Section II, Part B, Mandatory Appendix II

(3) a Code Case material specification

UG-10.2 Recertification of Identified Material. A Certificate Holder shall recertify per UG-10.2.1 or UG-10.2.2 a material meeting the following criteria:

(a) The material is identified with a specification not permitted by this Division.

(b) The material is identified to a single lot as required by a specification permitted by this Division.

(c) The material has marking acceptable to the Inspector that identifies the material to the documentation.

See UG-10.3 for recertification of material that does not meet the criteria of (a), (b), and (c).

UG-10.2.1 Recertification When Documentation Is Available.

(a) The material manufacturer shall provide to the Certificate Holder documentation that the material meets all the requirements of a specification permitted by this Division.

(b) After establishing the material's conformance to the permitted specification, the Certificate Holder shall mark the material as required by the permitted specification identified in (a).

UG-10.2.2 Recertification When Complete Documentation Is Unavailable. If the complete documentation described in UG-10.2.1(a) is unavailable, the Certificate Holder shall meet the requirements in 10.2.2.1 through 10.2.2.5.

UG-10.2.2.1 Missing Chemical Requirements Documentation. If documentation demonstrating complete conformance to the chemical requirements is not available, the Certificate Holder shall perform chemical analyses as described in (a) through (d).

(a) The Certificate Holder shall select a sample of random pieces from the lot of material for chemical analysis. The number of pieces in the sample shall be at least

$$\min\left[\max(0.10n, 3), n\right]$$

where

n = number of pieces in the lot

(b) The Certificate Holder shall analyze each piece in the sample per the chemical analyses described in the permitted specification.

(c) The Certificate Holder shall analyze those elements for which the permitted specification (including its general requirements specification) requires analysis and for which documentation is unavailable.

(d) To qualify for recertification, the material shall satisfy the following criteria:

(1) Each individual analysis for an element shall conform to the product analysis limits of the permitted specification.

(2) The average of each element shall conform to the heat analysis limits of the permitted specification.

UG-10.2.2.2 Missing Mechanical Requirements Documentation.

(a) The Certificate Holder shall test all mechanical properties for which required documentation is unavailable.

(b) The Certificate Holder shall perform the tests per the requirements of the permitted specification.

(c) The results of the mechanical properties tests shall conform to the requirements of the permitted specification.

UG-10.2.2.3 Missing Heat Treatment Requirements Documentation. If documentation demonstrating complete conformance to the heat treatment requirements is not available, the Certificate Holder shall heat treat the material per the requirements of the permitted specification. The heat treatment may be done before or during fabrication (see also UG-85).

UG-10.2.2.4 Other Requirements. The Certificate Holder shall demonstrate that the material meets all other applicable requirements of the permitted specification.

UG-10.2.2.5 Marking and Acceptance. After establishing per UG-10.2.2.1 through UG-10.2.2.4 the material's conformance to the permitted specification, the Certificate Holder shall mark the material as required by the permitted specification.

UG-10.3 Recertification of Material Not Fully Identified. A Certificate Holder may recertify per UG-10.3.1 and UG-10.3.2 a material that cannot be recertified per UG-10.2. UG-10.3.1 and UG-10.3.2 apply to material meeting either of the following criteria:

(a) The material is not fully identified as required by a specification permitted by this Division.

(b) The material is unidentified.

UG-10.3.1 Recertification Requirements. The Certificate Holder shall perform the following steps:

(a) Test each piece of material to show that it meets the chemical composition for heat analysis of the permitted specification. Chemical analyses shall be made for those elements required by the permitted specification (including its general requirements specification).

(b) Test each piece of material to show that it meets the mechanical properties requirements of the permitted specification.

(c) When the direction of final rolling or major work (as required by the material specification) is not known, the Certificate Holder shall do the following:

(1) Take tension test specimens in each appropriate direction from each sampling location designated in the permitted specification.

(2) Ensure that all test results conform to the minimum requirements of the specification.

(3) Show that the tensile strength of at least one specimen conforms to the maximum requirement.

(d) Heat treat if required per UG-10.2.2.3.

(e) Demonstrate that the material meets all other applicable requirements of the permitted specification.

UG-10.3.2 Recertification Acceptance.

(a) After identifying the material per UG-10.3.1, the Certificate Holder shall mark the material with the following information:

(1) the number of the permitted specification and grade, type, or class, as applicable, of the material

(2) a serial number identifying the lot of material

(b) The Certificate Holder shall complete and certify a material report clearly labeled "Report on Tests of Nonidentified Material."

(c) The Inspector shall review the "Report on Tests of Nonidentified Material" [see (b)]. If accepted by the Inspector, the report shall constitute authority to use the material in lieu of material procured to the requirements of the permitted specification.

UG-11 PREFABRICATED OR PREFORMED PRESSURE PARTS

(a) Prefabricated or preformed pressure parts for pressure vessels that are subject to stresses due to pressure and that are furnished by others or by the Manufacturer of the completed vessel shall conform to all applicable requirements of this Division except as permitted in (b), (c), (d), (e), and (f) below. When the prefabricated or preformed parts are furnished with a nameplate that contains product identifying marks and the nameplate interferes with further fabrication or service, and where stamping on the material is prohibited, the Manufacturer of the completed vessel, with the concurrence of the Authorized Inspector, may remove the nameplate. The removal of the nameplate shall be noted in the "Remarks" section of the vessel Manufacturer's Data Report. The nameplate shall be destroyed. The rules of (b), (c), (d), and (e) below shall not be applied to welded shells or heads or to quick-actuating or quick-opening closures (see UG-35.2 and UG-35.3, respectively).

Parts furnished under the provisions of (b), (c), (d), and (f) need not be manufactured by a Certificate Holder. However, the Manufacturer of the completed vessel or Certification Mark–stamped part shall ensure that parts furnished under the provisions of (b) through (f) meet all of the applicable Code requirements such as UCS-79(d), UNF-79(a), UHA-44(a), and UHT-79(a). Prefabricated or preformed pressure parts may be supplied as follows:

(1) cast, forged, rolled, or die formed non-standard pressure parts

(2) cast, forged, rolled, or die formed standard pressure parts that comply with an ASME product standard, either welded or nonwelded

(3) cast, forged, rolled, or die formed standard pressure parts that comply with a standard other than an ASME product standard, either welded or nonwelded

(4) cast cylindrical acrylic shells meeting the requirements of Part UAS.

(b) Cast, Forged, Rolled, or Die Formed Non-standard Pressure Parts. Pressure parts such as shells, heads, removable doors, and pipe coils that are wholly formed by casting, forging, rolling, or die forming may be supplied basically as materials. All such parts shall be made of materials permitted under this Division, and the manufacturer of the part shall furnish identification in accordance with UG-93. Such parts shall be marked with the name or trademark of the parts manufacturer and

with such other markings as will serve to identify the particular parts with accompanying material identification. The Manufacturer of the completed vessel shall be satisfied that the part is suitable for the design conditions specified for the completed vessel in accordance with the rules of this Division.

(c) *Cast, Forged, Rolled, or Die Formed Standard Pressure Parts That Comply With an ASME Product Standard, Either Welded or Nonwelded*

(1) These are pressure parts that comply with an ASME product standard accepted by reference in UG-44(a). The ASME product standard establishes the basis for the pressure–temperature rating and marking unless modified in UG-44(a).

(2) Flanges and flanged fittings may be used at the pressure–temperature ratings specified in the appropriate standard listed in this Division.

(3) Materials for standard pressure parts shall be as follows:

(-a) as permitted by this Division or

(-b) as specifically listed in the ASME product standard

(4) When welding is performed it shall meet the following:

(-a) the requirements of UW-26(a), UW-26(b), and UW-26(c) and UW-27 through UW-40, or;

(-b) the welding requirements of ASME specification SA-234.

(5) Standard pressure parts as identified in UG-11(c) do not require inspection, identification in accordance with UG-93.1 or UG-93.2, or Partial Data Reports, provided the requirements of UG-11(c) are met.

(6) If postweld heat treatment is required by the rules of this Division, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the vessel to be marked with the Certification Mark.

(7) If radiography or other volumetric examination is required by the rules of this Division, it may be performed at one of the following locations:

(-a) the location of the Manufacturer of the completed vessel

(-b) the location of the pressure parts manufacturer

(8) Parts made to an ASME product standard shall be marked as required by the ASME product standard.

(9) The Manufacturer of the completed vessels shall have the following responsibilities when using standard pressure parts that comply with an ASME product standard:

(-a) Ensure that all standard pressure parts comply with applicable rules of this Division.

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed vessel.

(-c) When volumetric examination is required by the rules of this Division, obtain the completed radiographs, properly identified, with a radiographic inspection report, and any other applicable volumetric examination report.

(10) The Manufacturer shall fulfill these responsibilities by obtaining, when necessary, documentation as provided below, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested. The documentation shall contain at a minimum:

(-a) material used

(-b) the pressure–temperature rating of the part

(-c) the basis for establishing the pressure–temperature rating

(d) Cast, Forged, Rolled, or Die Formed Standard Pressure Parts That Comply With a Standard Other Than an ASME Product Standard, Either Welded or Nonwelded

(1) Standard pressure parts that are either welded or nonwelded and comply with a manufacturer's proprietary standard or a standard other than an ASME product standard may be supplied by

(-a) a Certificate Holder

(-b) a pressure parts manufacturer

(2) Parts of small size falling within this category for which it is impossible to obtain identified material or that may be stocked and for which identification in accordance with UG-93 cannot be obtained and are not customarily furnished, may be used for parts as described in UG-4(b).

(3) Materials for these parts shall be as permitted by this Division only.

(4) Requirements for welding and brazing are as follows:

(-a) When welding is performed, it shall meet the requirements of UW-26(a), UW-26(b), UW-26(c), and UW-27 through UW-40.

(-b) When brazing is performed, it shall meet the requirements of Part UB.

(5) Standard pressure parts as identified in (d) do not require inspection, identification in accordance with UG-93.1 or UG-93.2, or Partial Data Reports, provided the requirements of (d) are met.

(6) If postweld heat treatment is required by the rules of this Division, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the completed vessel.

(7) If radiography or other volumetric examination is required by the rules of this Division, it may be performed at one of the following locations:

(-a) the location of the Manufacturer of the completed vessel

(-b) the location of the parts Manufacturer

(-c) the location of the pressure parts manufacturer

(8) Marking for these parts shall be as follows:

(-a) with the name or trademark of the Certificate Holder or the pressure part manufacturer and any other markings as required by the proprietary standard or other standard used for the pressure part

(-b) with a permanent or temporary marking that will serve to identify the part with the Certificate Holder or the pressure parts manufacturer's written documentation of the particular items, and that defines the pressure–temperature rating of the part

(9) The Manufacturer of the completed vessels shall have the following responsibilities when using standard pressure parts:

(-a) Ensure that all standard pressure parts comply with applicable rules of this Division.

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed vessel.

(-c) When volumetric examination is required by the rules of this Division, obtain the completed radiographs, properly identified, with a radiographic inspection report, and any other applicable volumetric examination report.

(10) The Manufacturer of the completed vessel shall fulfill these responsibilities by one of the following methods:

(-a) Obtain, when necessary, documentation as provided below, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested, or;

(-b) Perform an analysis of the pressure part in accordance with the rules of this Division. [See also U-2(g).] This analysis shall be included in the documentation and shall be made available for examination by the Inspector when requested.

(11) The documentation shall contain at a minimum:

(-a) material used

(-b) the pressure–temperature rating of the part

(-c) the basis for establishing the pressure–temperature rating

(-d) a written certification by the pressure parts manufacturer that all welding and brazing complies with Code requirements

(**25**) *(e)* The Code recognizes that a Certificate Holder may fabricate parts in accordance with UG-11(d), and that are marked in accordance with UG-11(d)(8). In lieu of the requirement in UG-11(d)(4), the Certificate Holder may subcontract to an individual or organization not holding an ASME Certificate standard pressure parts that are fabricated to a standard other than an ASME product standard provided all the following conditions are met:

(1) The activities to be performed by the subcontractor are included within the Certificate Holder's Quality Control System.

(2) The Certificate Holder's Quality Control System provides for the following activities associated with subcontracting of joining operations, and these provisions shall be acceptable to the Manufacturer's Authorized Inspection Agency:

(-a) the joining processes permitted by this Division that are permitted to be subcontracted

(-b) joining operations

(-c) Authorized Inspection activities

(-d) placement of the Certificate Holder's marking in accordance with UG-11(d)(8)

(3) The Certificate Holder's Quality Control System provides for the requirements of UG-92 to be met at the subcontractor's facility.

(4) The Certificate Holder shall be responsible for reviewing and accepting the Quality Control Programs of the subcontractor.

(5) The Certificate Holder shall ensure that the subcontractor uses written procedures and joining operations that have been qualified as required by this Division.

(6) The Certificate Holder shall ensure that the subcontractor uses personnel that have been qualified as required by this Division.

(7) The Certificate Holder and the subcontractor shall describe in their Quality Control Systems the operational control of procedure and personnel qualifications of the subcontracted joining operations.

(8) The Certificate Holder shall be responsible for controlling the quality and ensuring that all materials and parts that are joined by subcontractors and submitted to the Inspector for acceptance, conform to all applicable requirements of this Division.

(9) The Certificate Holder shall describe in their Quality Control Systems the operational control for maintaining traceability of materials received from the subcontractor.

(10) The Certificate Holder shall receive approval for subcontracting from the Authorized Inspection Agency prior to commencing of activities.

(f) Cast Acrylic Shells

(1) Cast acrylic cylindrical shells meeting the requirements of Part UAS may be supplied as material.

(2) The acrylic cylindrical shell manufacturer shall provide certification that the acrylic shell has been constructed in accordance with all the requirements of Part UAS. The certification package shall include all certification documentation required by Part UAS, UAS-8 and ASME PVHO-1 Forms VP-1 through VP-4.

(3) The certification package shall be verified by the Authorized Inspector prior to the acrylic shell being installed into any part of the vessel.

(4) The Certificate Holder shall include the acrylic certification package and PVHO-1 Form VP-5 with Form U-1 or Form U-1A.

UG-12 BOLTS AND STUDS

(a) Bolts and studs may be used for the attachment of removable parts. Specifications, supplementary rules, and maximum allowable stress values for acceptable bolting materials are given in the tables referenced in UG-23.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1\frac{1}{2}$ diameters in length.

Studs greater than eight diameters in length may have an unthreaded portion that has the nominal diameter of the thread, provided the following requirements are met:

(1) the threaded portions shall be at least $1\frac{1}{2}$ diameters in length;

(2) the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion;

(3) a suitable transition shall be provided between the root diameter and the unthreaded portion; and

(4) particular consideration shall be given to any dynamic loadings.

UG-13 NUTS AND WASHERS

(a) Nuts shall conform to the requirements in the applicable Part of Subsection C (see UCS-11 and UNF-13). They shall engage the threads for the full depth of the nut.

(b) The use of washers is optional. When used, they shall be of wrought materials.

(25) UG-14 BARS

(a) General

(1) Bar materials shall conform to the requirements for bars or bolting in the applicable Part of Subsection C.

(2) A bar is defined as a solid section whose axial length is greater than its maximum cross-sectional dimension, with a nominally constant cross section throughout its length.

(3) A rod is defined as a bar with other than a square or rectangular cross section; the general term "bar" is used in this paragraph.

(b) Bars Used in Tension or Longitudinal Bending. Bars may be used in pressure vessel construction for pressure parts whose primary stresses are parallel to the axis of the bar, such as flange rings [see Mandatory Appendix 2, 2-2(d)], stiffening rings, frames for reinforced openings, stays and staybolts, and similar parts.

(c) Other Parts Machined From Bar. Pressure parts other than those in (b), such as hollow cylindrically shaped parts, heads, caps, tubesheets, flanges, elbows, return bends, tees, and header tees, may be machined directly from bar as provided below. (See Table UG-14-1.)

(1) Using a Reduction in Design Stresses. Parts may be machined from bar provided all the following requirements are met:

(-a) The minimum required thickness of the component is calculated using 50% of the following values, as appropriate:

(-1) the specified allowable stress

(-2) the "B" value for external pressure or compressive stress design

(-3) the yield and tensile strengths for rules using such criteria

(-b) The following surfaces shall be examined by the magnetic particle or liquid penetrant method in accordance with the requirements of Mandatory Appendix 6 or Mandatory Appendix 8, respectively (see Figure UG-14-1):

(-1) any surface that has a slope greater than 1:3 from the axis of the bar following final machining, except where accessibility prevents meaningful interpretation and characterization of imperfections

(-2) the cut surfaces of the weld preparations prior to welding

(-c) Bar having a minimum cross-sectional dimension greater than 8.00 in. (205 mm) shall also conform to the ultrasonic requirements of (2)(-b) and (2)(-c).

(2) Using Transverse Tension Testing and Ultrasonic Examination. As an alternative to (1), parts may be machined from bar without a reduction in design stresses provided all the following requirements are met:

(-a) Transverse Test Specimens

(-1) In addition to the tension test specimens required by the material specification, tension test specimens shall meet the following requirements:

(+a) They shall be taken transverse to the axis of the bar per the requirements of (-2).

(+b) They shall be sampled from each lot (as defined in the material specification) of bar material.

(+c) In addition to the per-lot requirement of (+b), bars in the same lot shall be sampled from each diameter in the lot.

(-2) Specimens shall be removed from the bar as shown in Figure UG-14-2.

(+a) Hollow Parts, Such as Hollow, Cylindrically Shaped Parts, and Ring, Slip-On, or Weld Neck Flanges. The axis of the two outer tension test specimens shall be located, as nearly as practicable, midway between the minimum inner and maximum outer surfaces of the finished part, as measured from the bar axis, and 90 deg around the perimeter from each other.

(+b) Solid Parts, Such as Heads, Caps, Tubesheets, Blind Flanges, Elbows, Return Bends, Tees, and Header Tees

(+1) The axis of the two outer tension test specimens shall be located as nearly as practicable to the outer surface of the finished part, as measured from the bar axis, and 90 deg around the perimeter from each other.

(+2) The axis and mid-gage length of the third specimen shall be located approximately at the centerline of the bar; its orientation need not be aligned with either of the two other specimens.

(-3) All specimens shall meet all the mechanical tension test property requirements of the material specification.

(-b) Ultrasonic Examination. Each bar, before machining, shall be 100% ultrasonically examined perpendicular to the longitudinal axis by the straight beam

technique in accordance with Section V, SA-388 or SA-745, as applicable. The bar shall be unacceptable if either of the following occurs:

(-1) The examination results show one or more indications accompanied by loss of back reflection larger than 60% of the reference back reflection.

(-2) The examination results show indications larger than 40% of the reference back reflection when accompanied by a 40% loss of back reflection.

(-c) Longitudinal Ultrasonic Examination. For machined features of components for which it is practicable, such as heads, tubesheets and the flat portion of caps, the ultrasonic examination perpendicular to the longitudinal axis of (-b) shall also be performed in the axial direction. If the axial ultrasonic examination is qualified for the bar prior to machining, this ultrasonic examination may be done in lieu of the examination perpendicular to the longitudinal axis per (-b).

(-d) Surface Examination. Each part shall be surface examined per (1)(-b).

(3) Exemptions. The following are exemptions to the requirements of (c):

(-a) ASME Standard Parts. The requirements of (1) and (2) do not apply to parts conforming to an ASME standard per UG-11(c).

(-b) Proof-Tested Parts. The requirements of (1)(-a) and (2) do not apply to parts that use the provisions of UG-101. Only the requirements of (1)(-b) and (1)(-c) apply.

(25) UG-15 PRODUCT SPECIFICATION

When a material specification is not listed in this Division covering a particular wrought or hot isostatically pressed material product of a grade (i.e., desired material), but there is an approved specification listed in this Division covering some other wrought or hot isostatically pressed material product of that grade (i.e., approved material), the desired material may be used provided the following conditions are met:

(a) The chemical, mechanical, heat treating, deoxidation, and grain size requirements shall conform to the approved material.

(b) Hot isostatically pressed material shall also meet the requirements of Section II, Part D, Mandatory Appendix 5, Table 5-100 and 5-600 and shall be limited to the classes of material itemized in the title of Section II, Part D, Mandatory Appendix 5, Table 5-100.

(c) The desired material shall be covered in a Section II specification.

(d) The stress values for the approved material given in the tables referenced in UG-23 shall be used.

(e) For the case of welded product forms without the addition of filler metal, the allowable stresses of the desired material shall be the appropriate approved material stress values multiplied by a factor of 0.85.

(f) The product shall not be pipe or tube fabricated by fusion welding with the addition of filler metal unless it is constructed as a pressure part in accordance with the rules of this Division.

(g) The material test reports shall reference the specifications used in producing the material and reference this paragraph.

DESIGN

UG-16 GENERAL (25)

The design of pressure vessels and vessel parts shall conform to the general design requirements in UG-16.1 through UG-16.4. In addition, design of pressure vessels and vessel parts shall conform to the specific requirements for *Design* given in the applicable Parts of Subsections B, C, and D.

(a) If the design rules for a component reside in this Division, without reference to Section VIII, Division 2, then the design rules of this Division apply, except that Mandatory Appendix 46 may be used as an alternative.

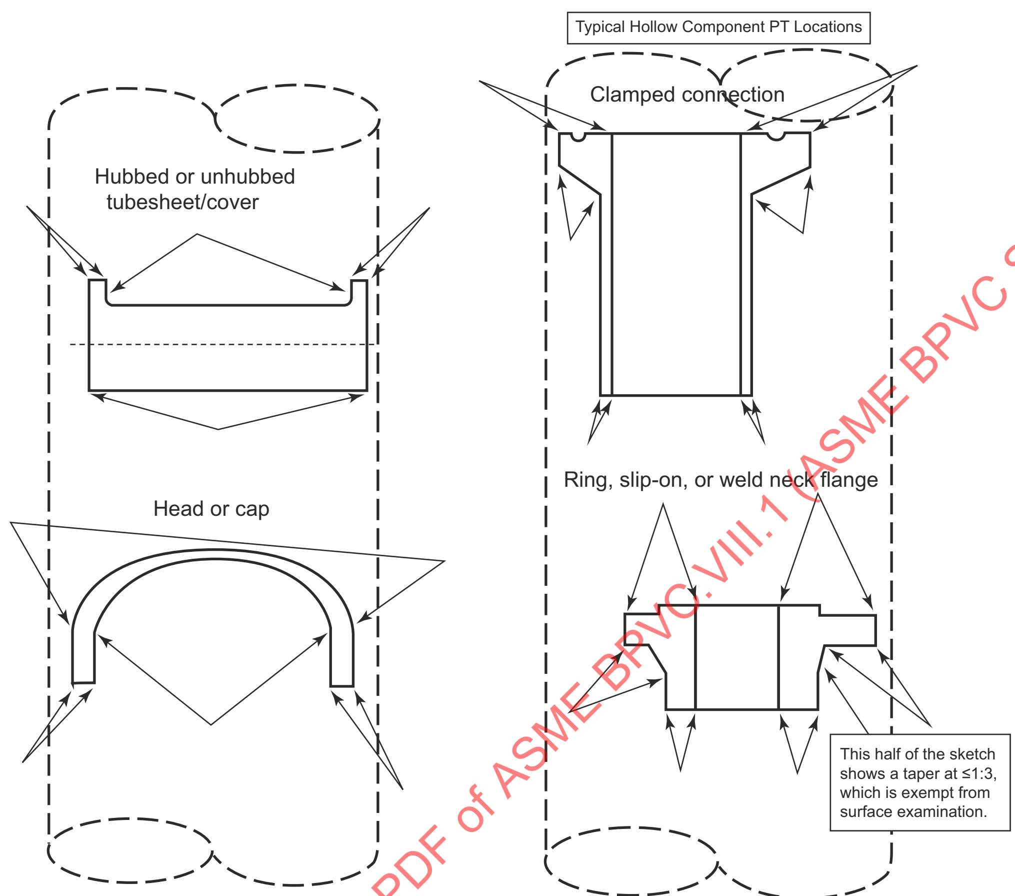
(b) If the design rules for a component refer to the design procedures in Section VIII, Division 2, then those design procedures shall be used subject to the conditions

Table UG-14-1 (25)
Criteria and Requirements for Bar per UG-14(c)

Direction of Primary Stresses Relative to the Bar Axis: Parallel	Not Parallel	Bar Nominal Size, in. (mm)	Design Stress Penalty Required per UG-14(c)(1)(-a), %	Volumetric Ultrasonic Examination Required per UG-14(c)(2)(-b) and UG-14(c)(2)(-c)	Transverse Tension Testing Required per UG-14(c)(2)(-a)	Surface Examination Required per UG-14(c)(1)(-b)
X	...	Any	None	None	None	None
...	X	≤8.00 (≤205)	50	None	None	X
...	X	>8.00 (>205)	50	X	None	X
...	X	Any	None	X	X	X

(25)

Figure UG-14-1
Typical Component Surface Examination Locations and Machined Features Requiring Axial Ultrasonic Examination



GENERAL NOTES:
(a) The areas between the arrows shall be surface examined.
(b) The features delineated between the arrows indicate examples of parts for which axial ultrasonic examination would be required, when practicable, in the machined part or in the bar prior to machining.

specified in the applicable appendix or paragraph in this Division. Requirements other than design shall be in accordance with this Division.

(c) For examples applying the design rules in this Division, see ASME PTB-4.

UG-16.1 Corrosion Allowance. Unless otherwise specified, all dimensions represented by dimensional symbols used in design equations throughout this Division are taken in the corroded condition.

UG-16.2 Minimum Thickness Requirements. The minimum thickness of the following components, after forming, regardless of product form or material, and exclusive of any corrosion allowance, shall be as follows:

(a) 0.25 in. (6 mm) for shells and heads of unfired steam boilers

(b) 0.0938 in. (2.5 mm) for shells and heads constructed from Table UCS-23 materials and used in compressed air service, steam service, or water service

(c) 0.022 in. (0.5 mm) for tubes used in air-cooled or cooling tower heat exchangers provided the tubes

(1) are not used in lethal service applications [see UW-2(a)]

(2) are protected by fins or other mechanical means, and

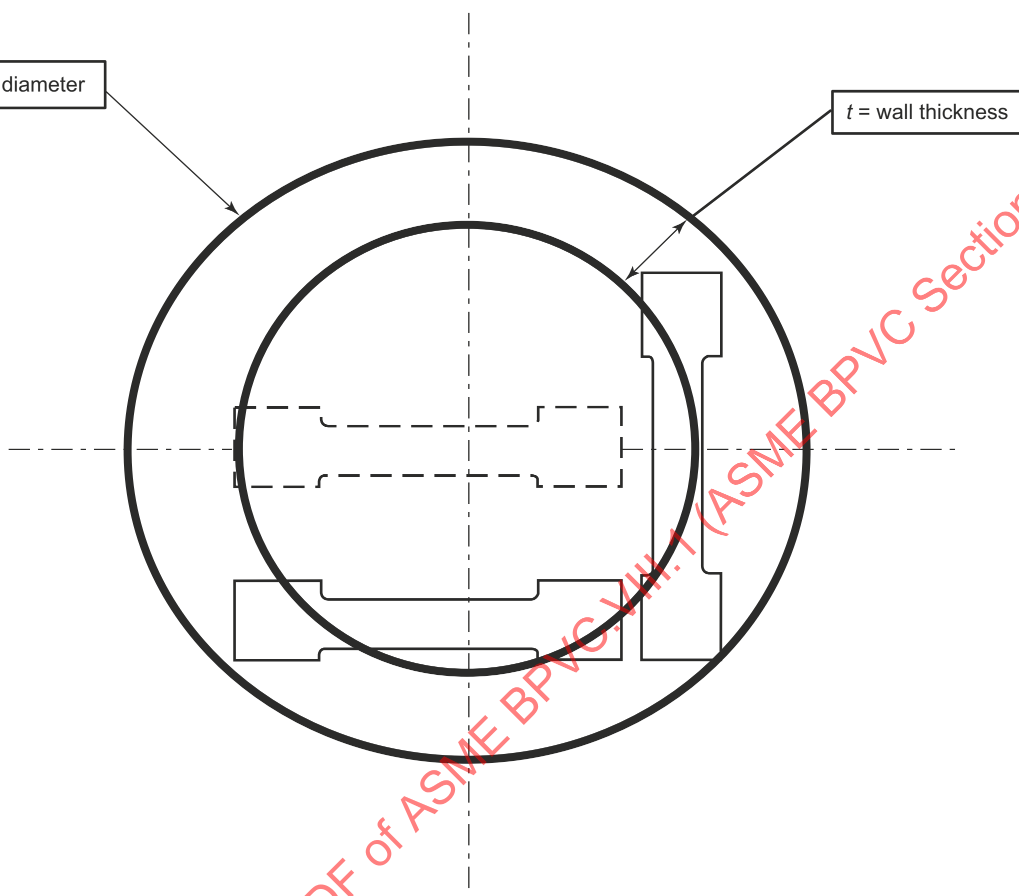
(3) have an outside diameter of 0.375 in. to 1.5 in. (10 mm to 38 mm), inclusive

(d) 0.0625 in. (1.5 mm) for all other components, unless otherwise specified in this Division

UG-16.3 Minimum Thickness Exemptions. Minimum thickness requirements do not apply to the following components:

(a) heat transfer plates of plate-type heat exchangers

Figure UG-14-2
Transverse Tension Test Specimen Locations and Orientations (25)



GENERAL NOTES:
(a) The thick solid outlines are illustrative of a finished part geometry.
(b) The thin solid specimens are the two mandatory locations.
(c) The thin dashed specimen is the third specimen when the centerline material remains in the finished part.

(b) the inner pipe of double-pipe heat exchangers and pipes and tubes NPS 6 (DN 150) or smaller shielded from mechanical damage by an outer protective element (such as a shell, casing, or duct), with the following provisions:

(1) This exemption applies regardless of whether the protective element is constructed to Code rules.

(2) The Manufacturer shall note on the Manufacturer's Data Report when the protective element is not provided as part of the vessel. The user or the user's designated agent shall ensure installation of the protective element prior to operation.

(3) Pressure buildup within the protective element due to a pipe or tube leak should be avoided and shall be accounted for in the design.

UG-16.4 Material Thickness Requirements. Material thickness shall be selected using the following criteria:

(a) Plate Undertolerance

(1) Plate material shall be ordered with a nominal thickness greater than or equal to the design thickness.

(2) Plate material shall not have a measured thickness less than the design thickness unless the difference in thickness is less than the minimum of 0.01 in. (0.3 mm) and 6% of the design thickness [see UG-90(b)(6)].

(3) A suitably larger nominal thickness shall be ordered if the material specification allows a manufacturing undertolerance greater than the minimum thickness difference in (2).

(b) Pipe Undertolerance

(1) Pipe and tube material ordered by nominal wall thickness shall have a nominal thickness greater than or equal to the design thickness plus the manufacturing undertolerance allowed by the applicable material specification.

(2) The requirement in (1) does not apply to the nozzle wall thickness defined in UG-37(a).

(c) Fabrication Allowance. The forming, heat treatment, and other fabrication processes shall not reduce the material thickness at any point below the required thickness.

UG-17 METHODS OF FABRICATION IN COMBINATION

A vessel may be designed and constructed by a combination of the methods of fabrication given in this Division, provided the rules applying to the respective methods of fabrication are followed and the vessel is limited to the service permitted by the method of fabrication having the most restrictive requirements (see UG-116).

UG-18 MATERIALS IN COMBINATION

Except as specifically prohibited by other rules of this Division, a vessel may be designed and constructed of any combination of materials permitted in Subsection C, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

The requirements for the base metals, HAZs, and weld metal(s) of a weldment between metals having different impact testing requirements and acceptance criteria shall each be applied in accordance with the rules of this Division.

NOTE: Because of the different thermal coefficients of expansion of dissimilar materials, caution should be exercised in design and construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts such as may occur at points of stress concentration and also because of metallurgical changes occurring at elevated temperatures. [See also *Galvanic Corrosion* in Section II, Part D, Nonmandatory Appendix A, A-440(c).]

(25) UG-19 SPECIAL CONSTRUCTIONS

(a) Combination Units. A combination unit is a pressure vessel that consists of more than one independent or dependent pressure chamber, operating at the same or different pressures and temperatures. The parts separating each pressure chamber are the common elements. Each element, including the common elements, shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation (see Mandatory Appendix 3, 3-2). This includes consideration of loads from chambers that are otherwise exempt from Code requirements per U-1(c)(2)(-f) and U-1(c)(2)(-g). Only the chambers that come within the scope of this Division (see U-1) need be constructed in compliance with its provisions. Also, see UJV-1(d) for jacketed vessels, and UG-99(e) or UG-100(d) for pressure tests of combination units.

(1) Common Element Design. It is permitted to design each common element for a differential pressure less than the maximum of the design pressures of its adjacent chambers (differential pressure design) or a mean metal temperature less than the maximum of the design temperatures of its adjacent chambers (mean metal temperature design), or both, only when the vessel is to be installed in a system that controls the common element design conditions.

(2) Differential Pressure Design (Dependent Pressure Chamber). When differential pressure design is permitted, the common element design pressure shall be the maximum differential design pressure expected between the adjacent chambers. The common element and its corresponding differential pressure shall be indicated in the "Remarks" section of the Manufacturer's Data Report [see UG-120(b)(1) and UHX-19.3] and marked on the vessel [see UG-116(j)(1)(-a) and UHX-19.2.1(a)]. The differential pressure shall be controlled to ensure the common element design pressure is not exceeded.

(3) Mean Metal Temperature Design. When mean metal temperature design is used, the maximum common element design temperature determined in accordance with UG-20(a) may be less than the greater of the maximum design temperatures of its adjacent chambers; however, it shall not be less than the lower of the maximum design temperatures of its adjacent chambers. The common element and its corresponding design temperature shall be indicated in the "Remarks" section of the Manufacturer's Data Report [see UG-120(b)(2) and UHX-19.3] and marked on the vessel [see UG-116(j)(1)(-b) and UHX-19.2.1(b)]. The fluid temperature, flow, and pressure, as required, shall be controlled to ensure the common element design temperature is not exceeded.

(b) Special Shapes. Vessels other than cylindrical and spherical and those for which no design rules are provided in this Division may be designed under the conditions set forth in U-2.

(c) When no design rules are given and the strength of a pressure vessel or vessel part cannot be calculated with a satisfactory assurance of accuracy, the maximum allowable working pressure of the completed vessel shall be established in accordance with the provisions of UG-101.

UG-20 DESIGN TEMPERATURE

(a) Maximum. Except as required in UW-2(d)(3), the maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered (see Mandatory Appendix 3, 3-2). If necessary, the metal temperature shall be determined by computation or by measurement from equipment in service under equivalent operating conditions. See also U-2(a).

NOTE: The user and Manufacturer are cautioned that certain fabrication details allowed by this Division may result in cracking at welds and associated heat-affected zones (HAZ) for vessels designed for use at elevated temperature. WRC Bulletin 470, "Recommendations for Design of Vessels for Elevated Temperature Service" has information that may prove helpful to the vessel designer. WRC Bulletin 470 contains recommended design details for use at elevated temperature service, which is for the purposes of this Division, when the allowable stresses in Section II, Part D are based on time-dependent properties. The use of these details does not relieve the Manufacturer of design responsibility with regard to consideration of stresses associated with both steady state conditions and transient events, such as startup, shutdown, intermittent operation, thermal cycling, etc., as defined by the user.

(b) Minimum. The minimum metal temperature used in design shall be the lowest expected in service except when lower temperatures are permitted by the rules of this Division[10] (see UG-116, UCS-66, and UCS-A-3). The minimum mean metal temperature shall be determined by the principles described in (a) above. Consideration shall include the lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling [except as permitted in (f)(3) below for vessels meeting the requirements of (f) below]. The MDMT marked on the nameplate shall correspond to a coincident pressure equal to the MAWP. When there are multiple MAWP's, the largest value shall be used to establish the MDMT marked on the nameplate. Additional MDMT's corresponding with other MAWP's may also be marked on the nameplate.[10]

(c) Design temperatures that exceed the temperature limit in the applicability column shown in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 are not permitted. In addition, design temperatures for vessels under external pressure shall not exceed the maximum temperatures given on the external pressure charts.

(d) The design of zones with different metal temperatures may be based on their determined temperatures.

(e) Suggested methods for obtaining the operating temperature of vessel walls in service are given in Nonmandatory Appendix C.

(f) Impact testing per UG-84 is not mandatory for pressure vessel materials that satisfy all of the following:

(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness, as defined in UCS-66(a) [see also Note (1) in Figure UCS-66.2], shall not exceed that given in (-a) or (-b) below:

(-a) $\frac{1}{2}$ in. (13 mm) for materials listed in Curve A of Figure UCS-66 (Figure UCS-66M);

(-b) 1 in. (25 mm) for materials listed in Curve B, C, or D of Figure UCS-66 (Figure UCS-66M).

(2) The completed vessel shall be hydrostatically tested per UG-99(b) or UG-99(c) or UGL-4. Alternatively, the completed vessel may be pneumatically tested in accordance with 35-6.

(3) Design temperature is no warmer than 650°F (345°C) nor colder than −20°F (−29°C). Occasional operating temperatures colder than −20°F (−29°C) are acceptable when due to lower seasonal atmospheric temperature.

(4) The thermal or mechanical shock loadings are not a controlling design requirement. (See UG-22.)

(5) Cyclical loading is not a controlling design requirement. (See UG-22.)

UG-21 DESIGN PRESSURE[11]

Each element of a pressure vessel shall be designed for at least the most severe condition of coincident pressure (including coincident static head in the operating position) and temperature expected in normal operation. For this condition, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered [see UG-98 and Mandatory Appendix 3, 3-2]. See also U-2(a).

UG-22 LOADINGS

The loadings to be considered in designing a vessel shall include those from:

(a) internal or external design pressure (as defined in UG-21);

(b) weight of the vessel and normal contents under operating or test conditions;

(c) superimposed static reactions from weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation;

(d) the attachment of:

(1) internals (see Nonmandatory Appendix D);

(2) vessel supports, such as lugs, rings, skirts, saddles, and legs (see Nonmandatory Appendix G);

(e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel, and mechanical loadings;

(f) wind, snow, and seismic reactions, where required;

(g) impact reactions such as those due to fluid shock;

(h) temperature gradients and differential thermal expansion;

(i) abnormal pressures, such as those caused by deflagration;

(j) test pressure and coincident static head acting during the test (see UG-99).

UG-23 MAXIMUM ALLOWABLE STRESS VALUES[12] (25)

(a) The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. The maximum allowable tensile stress values permitted for different materials are given in Section II, Part D, Subpart 1. Section II, Part D is published as two separate publications. One publication contains values only in the U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction. A listing of these materials is given in the following tables, which are included in Subsection C. For material identified as meeting more than one material specification and/or grade, the maximum allowable tensile stress value for either material specification and/or grade may be used provided all

requirements and limitations for the material specification and grade are met for the maximum allowable tensile stress value chosen.

Table	Title
UCS-23	Carbon and Low Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other carbon steels)
UNF-23.1 through UNF-23.5	Nonferrous Metals (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1B for other nonferrous metals)
UHA-23	High Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A or Table 1B for other high alloy steels)
UCI-23	Maximum Allowable Stress Values in Tension for Cast Iron
UCD-23	Maximum Allowable Stress Values in Tension for Cast Ductile Iron
UHT-23	Ferritic Steels with Properties Enhanced by Heat Treatment (stress values in Section II, Part D, Subpart 1, Table 1A)
ULT-23	Maximum Allowable Stress Values in Tension for 5%, 8%, and 9% Nickel Steels and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

The methods for determining maximum allowable stress values for impervious graphite (Certified Material) are given in UIG-23.

(b) The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined by the following procedure where

E = modulus of elasticity of material at design temperature. The modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.)

R_o = outside radius of cylindrical shell or tube

t = the minimum required thickness of the cylindrical shell or tube

The joint efficiency for butt-welded joints shall be taken as unity.

The value of B shall be determined as follows.

Step 1. Using the selected values of t and R_o, calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of t and R_o used in Step 1.

Step 4. For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

If tabulated values are used, determine B as in Step 2 and apply it to the equation in Step 4.

Step 5. Compare the value of B determined in Step 3 or Step 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of t and R_o. If the value of B is smaller than the computed compressive stress, a greater value of t must be selected and the design procedure repeated until a value of B is obtained that is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

(c) The wall thickness of a vessel computed by these rules shall be determined such that, for any combination of loadings listed in UG-22 that induce primary stress and are expected to occur simultaneously during normal operation[13] of the vessel, the induced maximum general primary membrane stress does not exceed the maximum allowable stress value in tension (see UG-23), except as provided in (d) below. Except where limited by special rules, such as those for cast iron in flanged joints, the above loads shall not induce a combined maximum primary membrane stress plus primary bending stress across the thickness that exceeds $1^1/_2$ times[14] the maximum allowable stress value in tension (see UG-23). It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience.

The maximum allowable stress values that are to be used in the thickness calculations are to be taken from the tables at the temperature that is expected to be maintained in the metal under the conditions of loading being considered. Maximum stress values may be interpolated for intermediate temperatures.

(d) For the combination of earthquake loading, or wind loading with other loadings in UG-22, the wall thickness of a vessel computed by these rules shall be determined such that the general primary membrane stress shall not exceed 1.2 times the maximum allowable stress permitted in (a), (b), or (c) above. This rule is applicable to stresses caused by internal pressure, external pressure, and axial compressive load on a cylinder.[15]

Earthquake loading and wind loading need not be considered to act simultaneously.

(e) Localized discontinuity stresses [see (c) above] are calculated in Mandatory Appendix 1, 1-5(g) and 1-8(e), Part UHX, and Part UEJ. The primary plus secondary stresses[14] at these discontinuities shall be limited to S_{PS}, where S_{PS} = 3S, and S is the maximum allowable stress of the material at temperature [see (a) above].

In lieu of using S_{PS} = 3S, a value of S_{PS} = 2S_Y may be used, where S_Y is the yield strength at temperature, provided the following are met:

(1) the allowable stress of material S is not governed by time-dependent properties as provided in Section II, Part D, Subpart 1, Table 1A or Table 1B;

(2) the room temperature ratio of the specified minimum yield strength to specified minimum tensile strength for the material does not exceed 0.7;

(f) Values for yield strength, S_Y, as a function of temperature are provided in Section II, Part D, Subpart 1, Table Y-1. If the material being used is not listed in Table Y-1, while being listed in other tables of Section II, Part D, Subpart 1, or the specified temperature exceeds the highest temperature for which a value is provided, the yield strength may be determined as described below for use in the design equations in this Division. S is the maximum allowable stress at the temperature specified [see (a)] and f is the factor (e.g., weld factor) used to determine the allowable stress as indicated in the notes for the stress line. If the value of f is not provided, set f equal to 1.

(1) If allowable stress is established based on the $66^2/_3$% yield criterion, then yield strength, S_Y, shall be taken as 1.5S/f.

(2) If the allowable stress is established based on yield criterion between $66^2/_3$% and 90%, then the yield strength, S_Y, shall be taken as 1.1S/f.

NOTE: For temperatures where the allowable stress, S, is based on time-dependent properties, the yield strength obtained by these formulas may be overly conservative.

(g) Maximum shear stress in restricted shear, such as dowel bolts or similar construction in which the shearing member is so restricted that the section under consideration would fail without a reduction of area, shall be limited to 0.80 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

(h) Maximum bearing stress shall be limited to 1.60 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

UG-24 CASTINGS (25)

UG-24.1 General Requirements.

(a) Surface Finish for Centrifugal Castings — All Materials. Machine all surfaces after heat treatment (when applicable) to a finish not coarser than 250 μin. (6.3 μm) arithmetical average deviation.

(b) Material Specification. All castings shall meet the minimum requirements of the material specification.

(c) Mandatory Appendix 7. Radiographic, liquid penetrant, and magnetic particle examination techniques and acceptance standards are given in Mandatory Appendix 7.

UG-24.2 Casting Quality Factors.

UG-24.2.1 General.

(a) Except for castings permitted by Part UCI, apply a casting quality factor, as specified in (b), to the allowable stress values for cast materials given in Subsection C.

(b) Apply the lesser of the following values at a welded joint in a casting:

(1) the quality factor specified in UG-24.2.2, UG-24.2.3, or UG-24.3

(2) the weld joint efficiency specified in UW-12

UG-24.2.2 Default Quality Factors — All Materials. Unless the additional requirements of UG-24.2.3 are met or UG-24.3 is required for lethal service, the following quality factors shall be used based on casting process:

(a) Static Castings. The quality factor shall not exceed 80%.

(b) Centrifugal Castings. The quality factor shall not exceed 85%.

UG-24.2.3 Quality Factors — Specific Materials.

UG-24.2.3.1 Nonferrous and Ductile Cast Iron Materials (See Part UNF or Part UCD, as Applicable). The quality factor shall not exceed 90% when castings of nonferrous and ductile cast iron material comply with UG-24.2.3.1 or UG-24.2.3.2.

UG-24.2.3.1.1 Multiple Castings.

(a) Visually examine all surfaces of each casting, particularly those surfaces exposed by machining or drilling.

(b) Dissect at all critical sections[16] or examine according to UG-24.2.3.1.2 at least three pilot castings[17] representing the first lot of five castings made from a new or altered design.

(c) Section or radiograph, at all critical sections, one more casting taken at random from every next lot of five.

(d) Examine all castings other than those that have been radiographed at all critical sections by the magnetic particle or liquid penetrant technique.

(e) The examination of samples in (b) and (c) shall not reveal any defects.

UG-24.2.3.1.2 Single Casting. A single casting shall meet one of the following requirements:

(a) The user or user's designated agent shall radiograph the casting at all critical sections.

(b) Machine a casting to the extent that all critical sections are exposed for examination as applicable for the full wall thickness, such as in tubesheets drilled with holes spaced no farther apart than the wall thickness of the casting.

UG-24.2.3.2 Carbon, Low Alloy, or High Alloy Steel Materials (See Part UCS, Part UHT, or Part UHA, as Applicable). Higher quality factors may be applied for these materials if the additional examinations of UG-24.2.3.2.1 or UG-24.2.3.2.2 are made.

UG-24.2.3.2.1 Static Castings. The quality factor shall not exceed 100% if the castings are radiographed and examined by the magnetic particle or liquid penetrant technique.

UG-24.2.3.2.2 Centrifugal Castings.

(a) The quality factor shall not exceed 90% if the castings are examined by the magnetic particle or liquid penetrant technique.

(b) The quality factor shall not exceed 100% if the castings are radiographed and examined by the magnetic particle or liquid penetrant technique.

UG-24.3 Lethal Service. The additional requirements of UG-24.3.1 through UG-24.3.3 apply when castings (including those permitted in UG-11) are to be used in vessels containing lethal substances (see UW-2).

UG-24.3.1 Cast Iron and Cast Ductile Iron. Cast iron (see UCI-2) and cast ductile iron castings (see UCD-2) shall not be used in lethal service.

UG-24.3.2 Nonferrous Castings. The quality factor shall not exceed 90% if nonferrous castings are radiographed at all critical sections.

UG-24.3.3 Steel Castings. The quality factor shall not exceed 100% for steel castings that have been examined for severe service applications [see Mandatory Appendix 7, 7-3(b)].

UG-24.4 Defects. Castings with defects shall be rejected or repaired by welding. Defects are imperfections defined as unacceptable by the more restrictive of the following:

(a) the material specification

(b) Mandatory Appendix 7, 7-3

UG-24.4.1 Defects Repaired by Welding.

(a) The completed repair shall be subject to reexamination in accordance with the applicable requirements of UG-24.2 or UG-24.3 and Mandatory Appendix 7, 7-4.

(b) The completed repair shall be subject to postweld heat treatment if required by any of the following:

(1) the rules of this Division

(2) the casting specification

(3) to obtain a 90% or 100% quality factor following UG-24.2.3.1, UG-24.2.3.2, UG-24.3.2, or UG-24.3.3

UG-24.5 Identification and Marking. Use the following identifications and markings in addition to those required by the material specification when a quality factor greater than 80% is applied:

(a) the manufacturer's identification, name, trademark, or other traceable identification

(b) the casting identification, including the quality factor and the material designation

UG-25 CORROSION (25)

(a) The user or the user's designated agent (see U-2) shall specify corrosion allowances other than those required by the rules of this Division. Where corrosion allowances are not provided, this fact shall be indicated on the Data Report.

(b) Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection. (See Nonmandatory Appendix E.)

NOTE: When using high alloys and nonferrous materials either for solid wall or clad or lined vessels, refer to UHA-6, UCL-3, and UNF-4, as appropriate.

(c) Material added for these purposes need not be of the same thickness for all parts of the vessel if different rates of attack are expected for the various parts.

(d) No additional thickness need be provided when previous experience in like service has shown that corrosion does not occur or is of only a superficial nature.

(e) Telltale Holes. Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. Telltale holes shall not be used in vessels that are to contain lethal substances [see UW-2(a)], except as permitted by ULW-76 for vent holes in layered construction. When telltale holes are provided, they shall have a diameter of $^1/_{16}$ in. to $^3/_{16}$ in. (1.5 mm to 5 mm)and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the opposite surface to that where deterioration is expected. [For telltale holes in clad or lined vessels, see UCL-25(b).]

(f) Openings for Drain. Vessels subject to internal corrosion shall be supplied with a suitable drain opening at the lowest point practicable in the vessel; or a pipe may be used extending inward from any other location to within $^1/_4$ in. (6 mm) of the lowest point.

UG-26 LININGS

Corrosion resistant or abrasion resistant linings, whether or not attached to the wall of a vessel, shall not be considered as contributing to the strength of the wall except as permitted in Part UCL (see Nonmandatory Appendix F).

UG-27 THICKNESS OF SHELLS UNDER INTERNAL PRESSURE

(a) The minimum required thickness of shells under internal pressure shall not be less than that computed by the following formulas,[18] except as permitted by Mandatory Appendix 1 or Mandatory Appendix 32. In addition, provision shall be made for any of the loadings listed in UG-22, when such loadings are expected. The provided thickness of the shells shall also meet the requirements of UG-16, except as permitted in Mandatory Appendix 32.

(b) The symbols defined below are used in the formulas of this paragraph.

E = joint efficiency for, or the efficiency of, appropriate joint in cylindrical or spherical shells, or the efficiency of ligaments between openings, whichever is less.
For welded vessels, use the efficiency specified in UW-12.
For ligaments between openings, use the efficiency calculated by the rules given in UG-53.
P = internal design pressure (see UG-21)
R = inside radius of the shell course under consideration[19]
S = maximum allowable stress value (see UG-23 and the stress limitations specified in UG-24)
t = minimum required thickness of shell

(c) *Cylindrical Shells.* The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2) below.

(1) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385SE$, the following formulas shall apply:

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t} \qquad (1)$$

(2) Longitudinal Stress (Circumferential Joints).[20] When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE + 0.4P} \quad \text{or} \quad P = \frac{2SEt}{R - 0.4t} \qquad (2)$$

(d) *Spherical Shells.* When the thickness of the shell of a wholly spherical vessel does not exceed $0.356R$, or P does not exceed $0.665SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{R + 0.2t} \qquad (3)$$

(e) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

(f) A stayed jacket shell that extends completely around a cylindrical or spherical vessel shall also meet the requirements of UG-47(c).

(g) Any reduction in thickness within a shell course or spherical shell shall be in accordance with UW-9.

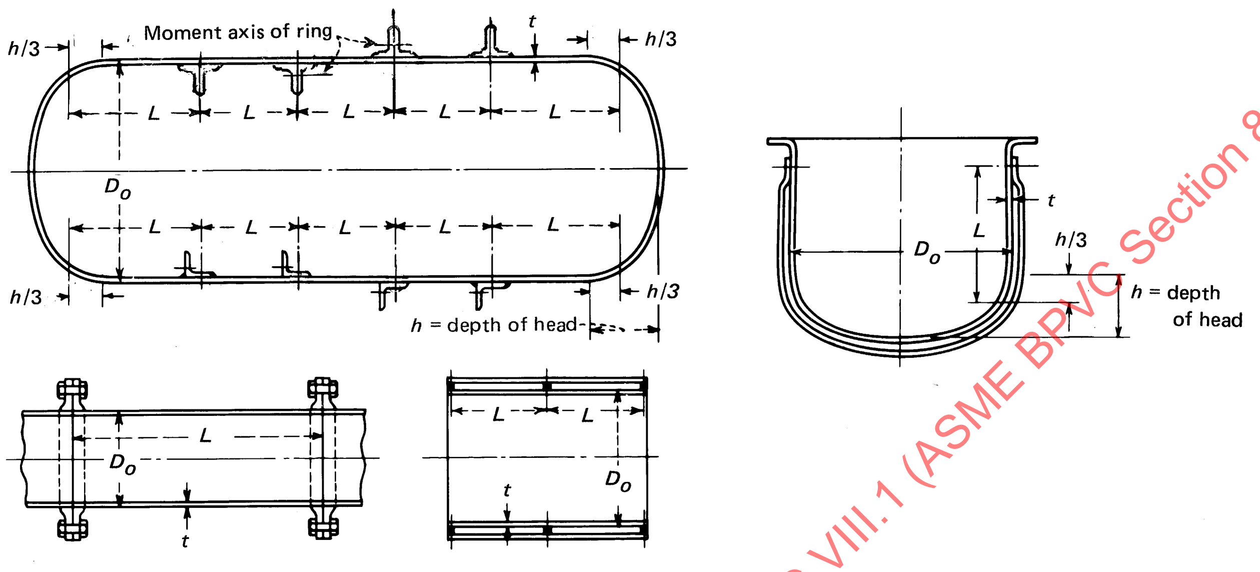
UG-28 THICKNESS OF SHELLS AND TUBES UNDER EXTERNAL PRESSURE (25)

(a) Rules for the design of shells and tubes under external pressure given in this Division are limited to cylindrical shells, with or without stiffening rings, tubes, and spherical shells. Three typical forms of cylindrical shells are shown in Figure UG-28. Charts used in determining minimum required thicknesses of these components are given in Section II, Part D, Subpart 3.

(b) The symbols defined below are used in the procedures of this paragraph:

A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/t values less than 10, see (c)(2).
B = factor determined from the applicable material chart or table in Section II, Part D, Subpart 3 for maximum design metal temperature [see UG-20(c)]
D_o = outside diameter of cylindrical shell course or tube
E = modulus of elasticity of material at design temperature. For external pressure design in accordance with this Section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.)
L = total length, in. (mm), of a tube between tubesheets, or design length of a vessel section between lines of support (see Figure UG-28.1). A line of support is:
(a) a circumferential line on a head (excluding conical heads) at one-third the depth of the head from the head tangent line as shown on Figure UG-28;
(b) a stiffening ring that meets the requirements of UG-29;

Figure UG-28
Diagrammatic Representation of Variables for Design of Cylindrical Vessels Subjected to External Pressure



(c) a jacket closure of a jacketed vessel that meets the requirements of Mandatory Appendix 9, 9-5;

(d) a cone-to-cylinder junction or a knuckle-to-cylinder junction of a toriconical head or section that satisfies the moment of inertia requirement of Mandatory Appendix 1, 1-8.

P = external design pressure [see Note in (f)]

P_a = calculated value of maximum allowable external working pressure for the assumed value of t, [see Note in (f) below]

R_o = outside radius of spherical shell

t = minimum required thickness of cylindrical shell or tube, or spherical shell, in. (mm)

t_s = nominal thickness of cylindrical shell or tube, in. (mm)

(c) Cylindrical Shells and Tubes. The required minimum thickness of a cylindrical shell or tube under external pressure, either seamless or with longitudinal butt joints, shall be determined by the following procedure:

(1) Cylinders having D_o/t values ≥ 10:

Step 1. Assume a value for t and determine the ratios L/D_o and D_o/t.

Step 2. Enter Section II, Part D, Subpart 3, Figure G at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o = 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o = 0.05.

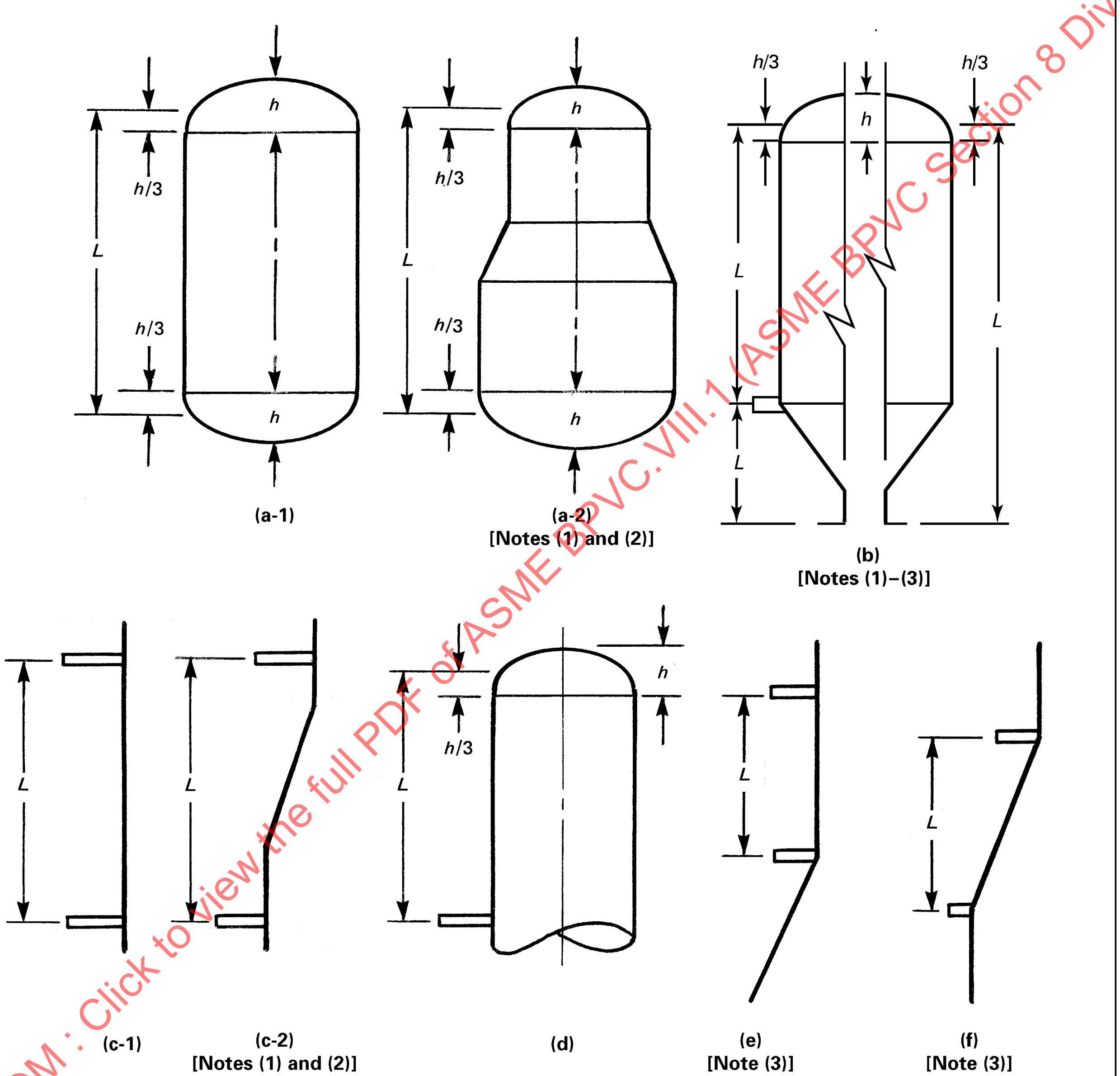
Step 3. Move horizontally to the line for the value of D_o/t determined in Step 1. Interpolation may be made for intermediate values of D_o/t; extrapolation is not permitted. From this point of intersection move vertically downward to determine the value of factor A. For values of A greater than 0.10, use a value of 0.10.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

Figure UG-28.1
Diagrammatic Representation of Lines of Support for Design of Cylindrical Vessels Subjected to External Pressure



NOTES:

(1) When the cone-to-cylinder or the knuckle-to-cylinder junction is not a line of support, the required thickness of the cone, knuckle, or toriconical section shall not be less than the required thickness of the adjacent cylindrical shell. Also, the reinforcement requirement of Mandatory Appendix 1, 1-8 shall be satisfied when a knuckle is not provided at the cone-to-cylinder junction.

(2) Calculations shall be made using the diameter and corresponding thickness of each cylindrical section with dimension L as shown. Thicknesses of the transition sections are based on Note (1).

(3) When the cone-to-cylinder or the knuckle-to-cylinder junction is a line of support, the moment of inertia shall be provided in accordance with Mandatory Appendix 1, 1-8 [see UG-33(f)].

Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following equation:

$$P_a = \frac{4B}{3(D_o/t)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o/t)}$$

If tabular values are used, determine B as in Step 4 and apply it to the equation in Step 6.

Step 8. Compare the calculated value of P_a obtained in Step 6 or Step 7 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P.

(2) Cylinders having D_o/t values <10:

Step 1. Using the same procedure as given in (1), obtain the value of B. For values of D_o/t less than 4, the value of factor A can be calculated using the following equation:

$$A = \frac{1.1}{(D_o/t)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following equation:

$$P_{a1} = \left[\frac{2.167}{(D_o/t)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following equation:

$$P_{a2} = \frac{2S}{D_o/t}\left[1 - \frac{1}{D_o/t}\right]$$

where S is the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable table referenced in UG-23, or 0.9 times the yield strength of the material at design temperature. Values of yield strength are obtained from the applicable external pressure chart as follows:

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

Step 4. The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(d) Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the following procedure:

Step 1. Assume a value for t and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B.

Step 4. Using the value of B obtained in Step 3, calculate the value of the maximum allowable external working pressure P_a using the following equation:

$$P_a = \frac{B}{(R_o/t)}$$

Step 5. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R_o/t)^2}$$

If tabulated values are used, determine B as in Step 2 and apply it to the equation in Step 4.

Step 6. Compare P_a obtained in Step 4 or Step 5 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(e) The external design pressure or maximum allowable external working pressure shall not be less than the maximum expected difference in operating pressure that may exist between the outside and the inside of the vessel at any time.

(f) Vessels intended for service under external design pressures of 15 psi (103 kPa) and less [see U-1(c)(2)(-h)] may be stamped with the Certification Mark and Designator denoting compliance with the rules for external pressure, provided all the applicable rules of this Division are satisfied. When the Certification Mark is to be applied, the user or the user's designated agent shall specify the required maximum allowable external working pressure.[21] The vessel shall be designed and stamped with the maximum allowable external working pressure.

(g) When there is a longitudinal lap joint in a cylindrical shell or any lap joint in a spherical shell under external pressure, the thickness of the shell shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(h) Circumferential joints in cylindrical shells may be of any type permitted by the Code and shall be designed for the imposed loads.

(i) Those portions of pressure chambers of vessels that are subject to a collapsing pressure and that have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels that extend over only a portion of the circumference, shall be fully staybolted in accordance with the requirements of UG-47 through UG-50 or shall be proof tested in compliance with UG-101(p).

(j) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

(25) UG-29 STIFFENING RINGS FOR CYLINDRICAL SHELLS UNDER EXTERNAL PRESSURE

(a) External stiffening rings shall be attached to the shell by welding or brazing [see UG-30]. Internal stiffening rings need not be attached to the shell when the rings are designed to carry the loads and adequate means of support is provided to hold the ring in place when subjected to external pressure loads. Segments of rings need not be attached when the requirements of (c) are met.

Except as exempted in (f) below, the available moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two formulas:

$$I_s = \left[D_o^2 L_s\left(t + A_s/L_s\right)A\right] / 14$$

$$I_s' = \left[D_o^2 L_s\left(t + A_s/L_s\right)A\right] / 10.9$$

where

I = available moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I_s = required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I' = available moment of inertia of combined ring-shell cross section about its neutral axis parallel to the axis of the shell. The nominal shell thickness t_s shall be used and the width of shell that is taken as contributing to the moment of inertia of the combined section shall not be greater than $1.10\sqrt{D_o t_s}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring.

I_s' = required moment of inertia of the combined ring-shell cross section about its neutral axis parallel to the axis of the shell

CAUTION: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I'_s [see U-2(g)].

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

A = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B, below, and the design temperature for the shell under consideration

A_s = cross-sectional area of the stiffening ring

B = factor determined from the applicable chart or table in Section II, Part D, Subpart 3 for the material used for the stiffening ring [see UG-20(c)]

L_s = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder. A line of support is:

(a) a stiffening ring that meets the requirements of this paragraph;

(b) a circumferential connection to a jacket for a jacketed section of a cylindrical shell;

(c) a circumferential line on a head at one-third the depth of the head from the head tangent line as shown on Figure UG-28;

(d) a cone-to-cylinder junction.

D_o, E, P, t, and t_s are as defined in UG-28(b).

The adequacy of the moment of inertia for a stiffening ring shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_o, L_s, and t are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s. Then calculate factor B using the following equation:

$$B = \frac{3}{4}\left(\frac{PD_o}{t + A_s/L_s}\right)$$

Step 2. See below.

(a) If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine an A value that lies between two adjacent tabular values for a specific temperature. Linear interpolation may also be used to determine an A value at an intermediate temperature that lies between two sets of tabular values, after first determining A values for each set of tabular values. The value of A so determined is then applied in the equation for I_s or I_s' in Step 6(a) or Step 6(b).

(b) If material charts in Section II, Part D, Subpart 3 are used, enter the right-hand side of the applicable material chart for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4, below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E$.

Step 6. See below.

(a) In those cases where only the stiffening ring is considered, compute the required moment of inertia from the formula for I_s given above.

(b) In those cases where the combined ring-shell is considered, compute the required moment of inertia from the formula for I_s' given above.

Step 7. See below.

(a) In those cases where only the stiffening ring is considered, determine the available moment of inertia I as given in the definitions.

(b) In those cases where the combined ring-shell is considered, determine the available moment of inertia I' as given in the definitions.

NOTE: In those cases where the stiffening ring is not attached to the shell or where the stiffening ring is attached but the designer chooses to consider only the ring, Step 6(a) and Step 7(a) are considered. In those cases where the stiffening ring is attached to the shell and the combined moment of inertia is considered, Step 6(b) and Step 7(b) are considered.

Step 8. If the required moment of inertia is greater than the available moment of inertia for the section selected, for those cases where the stiffening ring is not attached or where the combined ring-shell stiffness was not considered, a new section with a larger moment of inertia must be selected; the ring must be attached to the shell and the combination shall be considered; or the ring-shell combination that was previously not considered together shall be considered together. If the required moment of inertia is greater than the available moment of inertia for those cases where the combined ring-shell was considered, a new ring section with a larger moment of inertia must be selected. In any case, when a new section is used, all of the calculations shall be repeated using the new section properties of the ring or ring-shell combination.

If the required moment of inertia is smaller than the actual moment of inertia of the ring or ring-shell combination, whichever is used, that ring section or combined section is satisfactory.

(b) Stiffening rings shall extend completely around the circumference of the cylinder except as permitted in (c) below. Any joints between the ends or sections of such rings, such as shown in Figure UG-29.1 (A) and (B), and any connection between adjacent portions of a stiffening ring lying inside or outside the shell as shown in Figure UG-29.1 (C) shall be made so that the required moment of inertia of the combined ring-shell section is maintained.

(c) Stiffening rings placed on the inside of a vessel may be arranged as shown in Figure UG-29.1 (E) and (F), provided that the required moment of inertia of the ring in (E) or of the combined ring-shell section in (F) is maintained within the sections indicated. Where the gap at (A) or (E) does not exceed eight times the thickness of the shell plate, the combined moment of inertia of the shell and stiffener may be used.

Any gap in that portion of a stiffening ring supporting the shell, such as shown in Figure UG-29.1 (D) and (E), shall not exceed the length of are given in Figure UG-29.2 unless additional reinforcement is provided as shown in Figure UG-29.1 (C) or unless the following conditions are met:

(1) only one unsupported shell arc is permitted per ring; and

(2) the length of the unsupported shell arc does not exceed 90 deg; and

Figure UG-29.1
Various Arrangements of Stiffening Rings for Cylindrical Vessels Subjected to External Pressure

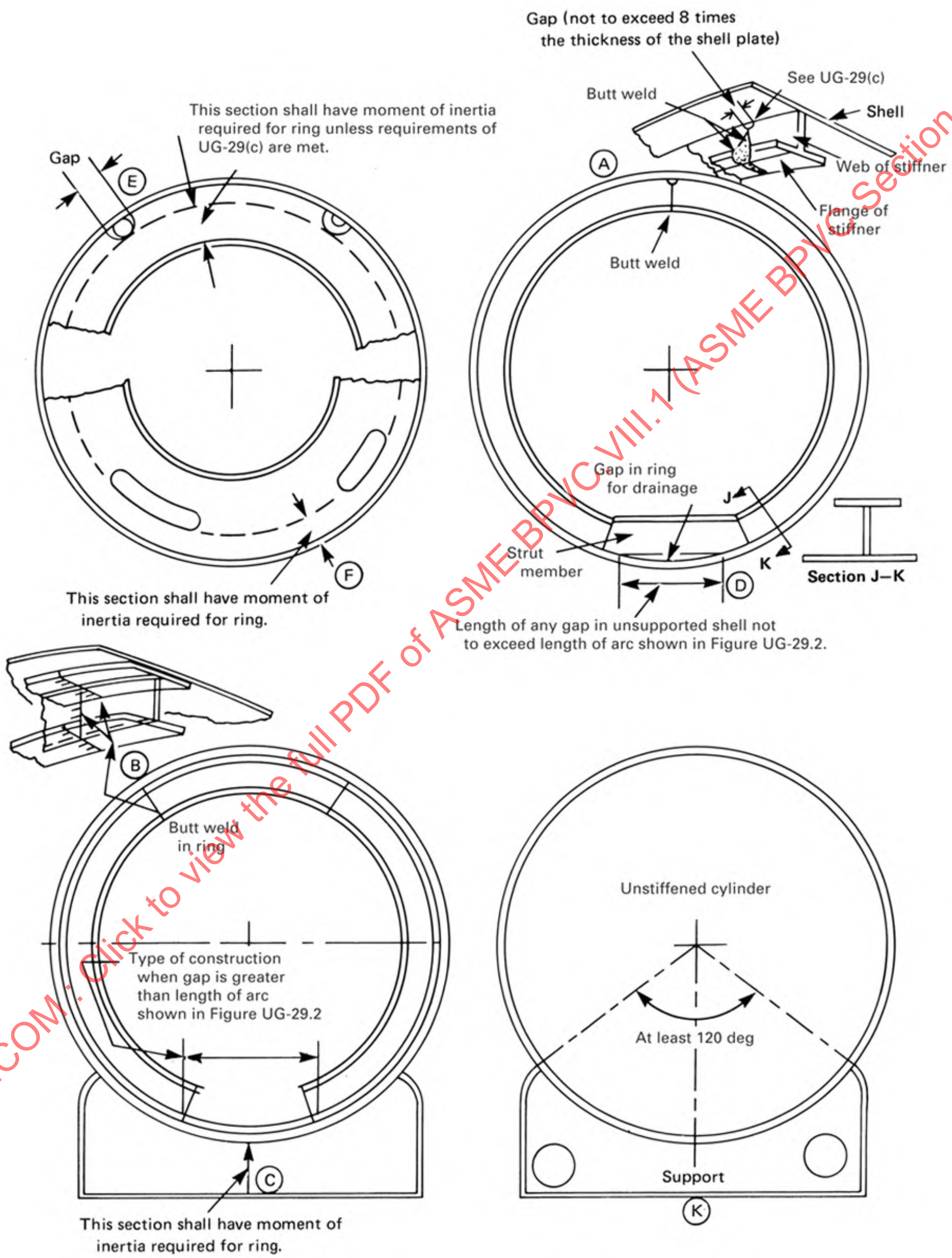
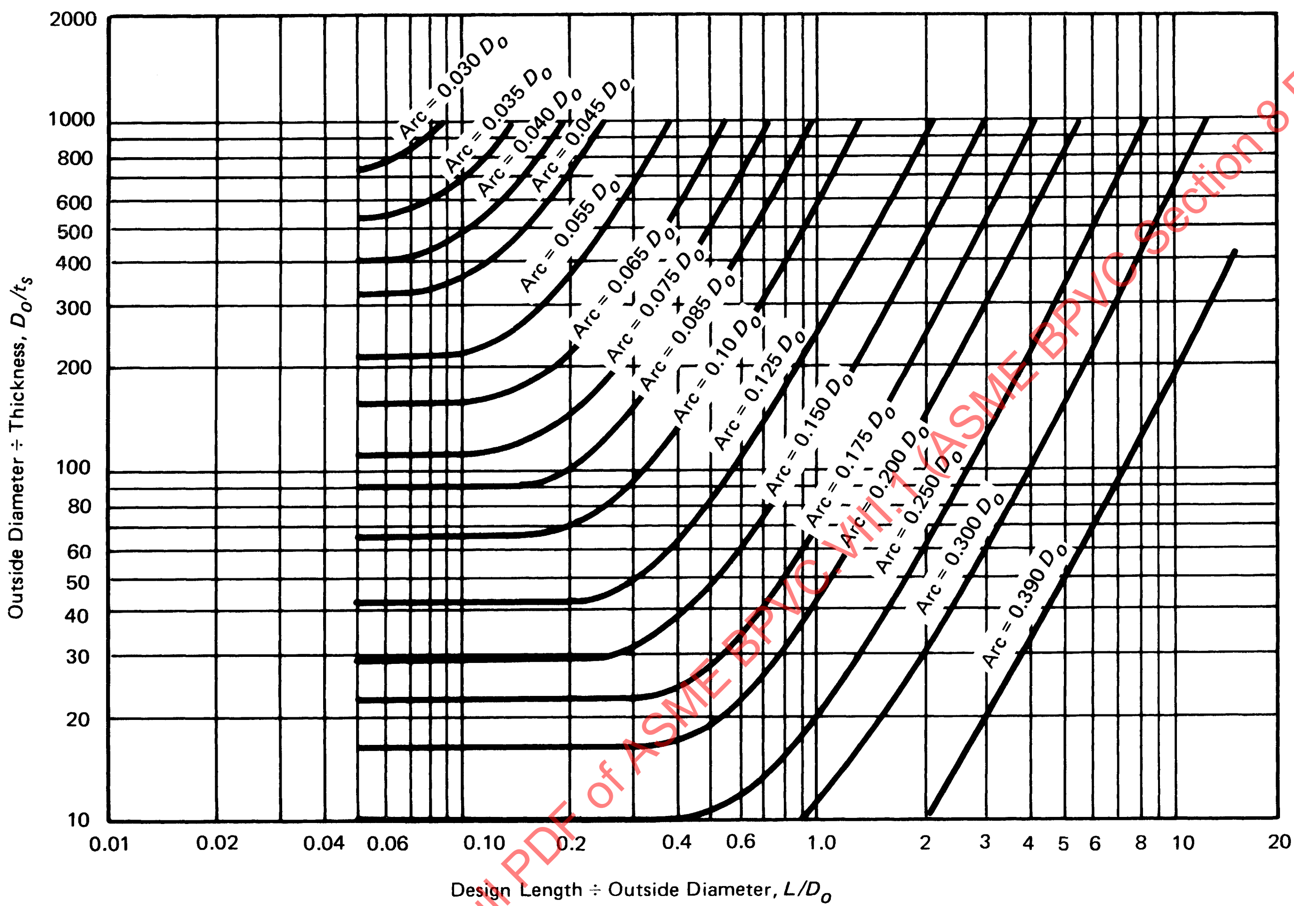


Figure UG-29.2
Maximum Arc of Shell Left Unsupported Because of Gap in Stiffening Ring of Cylindrical Shell Under External Pressure



(3) the unsupported arcs in adjacent stiffening rings are staggered 180 deg; and

(4) the dimension L defined in UG-28(b) is taken as the larger of the following: the distance between alternate stiffening rings, or the distance from the head tangent line to the second stiffening ring plus one-third of the head depth.

(d) When internal plane structures perpendicular to the longitudinal axis of the cylinder (such as bubble trays or baffle plates) are used in a vessel, they may also be considered to act as stiffening rings, provided they are designed to function as such.

(e) Any internal stays or supports used as stiffeners of the shell shall bear against the shell of the vessel through the medium of a substantially continuous ring.

NOTE: Attention is called to the objection to supporting vessels through the medium of legs or brackets, the arrangement of which may cause concentrated loads to be imposed on the shell. Vertical vessels should be supported through a substantial ring secured to the shell (see Nonmandatory Appendix G, G-3). Horizontal vessels, unless supported at or close to the ends (heads) or at stiffening rings, should be supported through the medium of substantial members extending over at least one-third of the circumference, as shown at (K) in Figure UG-29.1.

Attention is called also to the hazard of imposing highly concentrated loads by the improper support of one vessel on another or by the hanging or supporting of heavy weights directly on the shell of the vessel. (See Nonmandatory Appendix G.)

(f) When closure bars or other rings are attached to both the inner shell and outer jacket of a vessel, with pressure in the space between the jacket and inner shell, this construction has adequate inherent stiffness, and therefore the rules of this paragraph do not apply.

UG-30 ATTACHMENT OF STIFFENING RINGS

(a) Stiffening rings may be placed on the inside or outside of a vessel, and except for the configurations permitted by UG-29, shall be attached to the shell by welding or brazing. Brazing may be used if the vessel is not to be later stress relieved. The ring shall be essentially

in contact with the shell and meet the rules in UG-29(b) and UG-29(c). Welding of stiffening rings shall comply with the requirements of this Division for the type of vessel under construction.

(b) Stiffening rings may be attached to the shell by continuous, intermittent, or a combination of continuous and intermittent welds or brazes. Some acceptable methods of attaching stiffening rings are illustrated in Figure UG-30.

(c) Intermittent welding shall be placed on both sides of the stiffener and may be either staggered or in-line. Length of individual fillet weld segments shall not be less than 2 in. (50 mm) and shall have a maximum clear spacing between toes of adjacent weld segments of $8t$ for external rings and $12t$ for internal rings where t is the shell thickness at the attachment. The total length of weld on each side of the stiffening ring shall be:

(1) not less than one-half the outside circumference of the vessel for rings on the outside; and

(2) not less than one-third the circumference of the vessel for rings on the inside.

(d) A continuous full penetration weld is permitted as shown in sketch (e) of Figure UG-30. Continuous fillet welding or brazing on one side of the stiffener with intermittent welding or brazing on the other side is permitted for sketches (a), (b), (c), and (d) of Figure UG-30 when the thickness t_w of the outstanding stiffening element [sketches (a) and (c)] or width w of the stiffening element mating to the shell [sketches (b) and (d)] is not more than 1 in. (25 mm). The weld segments shall be not less than 2 in. (50 mm) long and shall have a maximum clear spacing between toes of adjacent weld segments of $24t$.

(e) Strength of Attachment Welds. Stiffening ring attachment welds shall be sized to resist the full radial pressure load from the shell between stiffeners, and shear loads acting radially across the stiffener caused by external design loads carried by the stiffener (if any) and a computed radial shear equal to 2% of the stiffening ring's compressive load.

(1) The radial pressure load from shell, lb/in., is equal to PL_s.

(2) The radial shear load is equal to $0.01PL_sD_O$.

(3) P, L_s, and D_O are defined in UG-29.

(f) Minimum Size of Attachment Welds. The fillet weld leg size shall be not less than the smallest of the following:

(1) $^1/_4$ in. (6 mm);

(2) vessel thickness at the weld location;

(3) stiffener thickness at weld location.

UG-31 TUBES, AND PIPE WHEN USED AS TUBES OR SHELLS

(a) Internal Pressure. The required wall thickness for tubes and pipe under internal pressure shall be determined in accordance with the rules for shells in UG-27.

(b) External Pressure. The required wall thickness for tubes and pipe under external pressure shall be determined in accordance with the rules in UG-28.

(c) The thickness as determined under (a) or (b) above shall be increased when necessary to meet the following requirements:

(1) Additional wall thickness should be provided when corrosion, erosion, or wear due to cleaning operations is expected.

(2) Where ends are threaded, additional wall thickness is to be provided in the amount of $0.8/n$ in. ($20/n$ mm) [where n equals the number of threads per inch (25.4 mm)].

NOTE: The requirements for rolling, expanding, or otherwise seating tubes in tube plates may require additional wall thickness and careful choice of materials because of possible relaxation due to differential expansion stresses.

UG-32 FORMED HEADS, AND SECTIONS, PRESSURE ON CONCAVE SIDE

(a) The minimum required thickness at the thinnest point after forming[22] of ellipsoidal, torispherical, hemispherical, conical, and toriconical heads under pressure on the concave side (plus heads) shall be computed by the appropriate formulas in this paragraph,[23] except as permitted by Mandatory Appendix 32. Heads with bolting flanges shall meet the requirements of UG-35.1. In addition, provision shall be made for any of the loadings listed in UG-22. The provided thickness of the heads shall also meet the requirements of UG-16, except as permitted in Mandatory Appendix 32.

(b) The symbols defined below are used in the formulas of this paragraph:

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis

D_i = inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone
= $D - 2r(1 - \cos \alpha)$

E = lowest efficiency of any joint in the head; for hemispherical heads this includes head-to-shell joint; for welded vessels, use the efficiency specified in UW-12

L = inside spherical or crown radius. The value of L for ellipsoidal heads shall be obtained from Table UG-37.

P = internal design pressure (see UG-21)

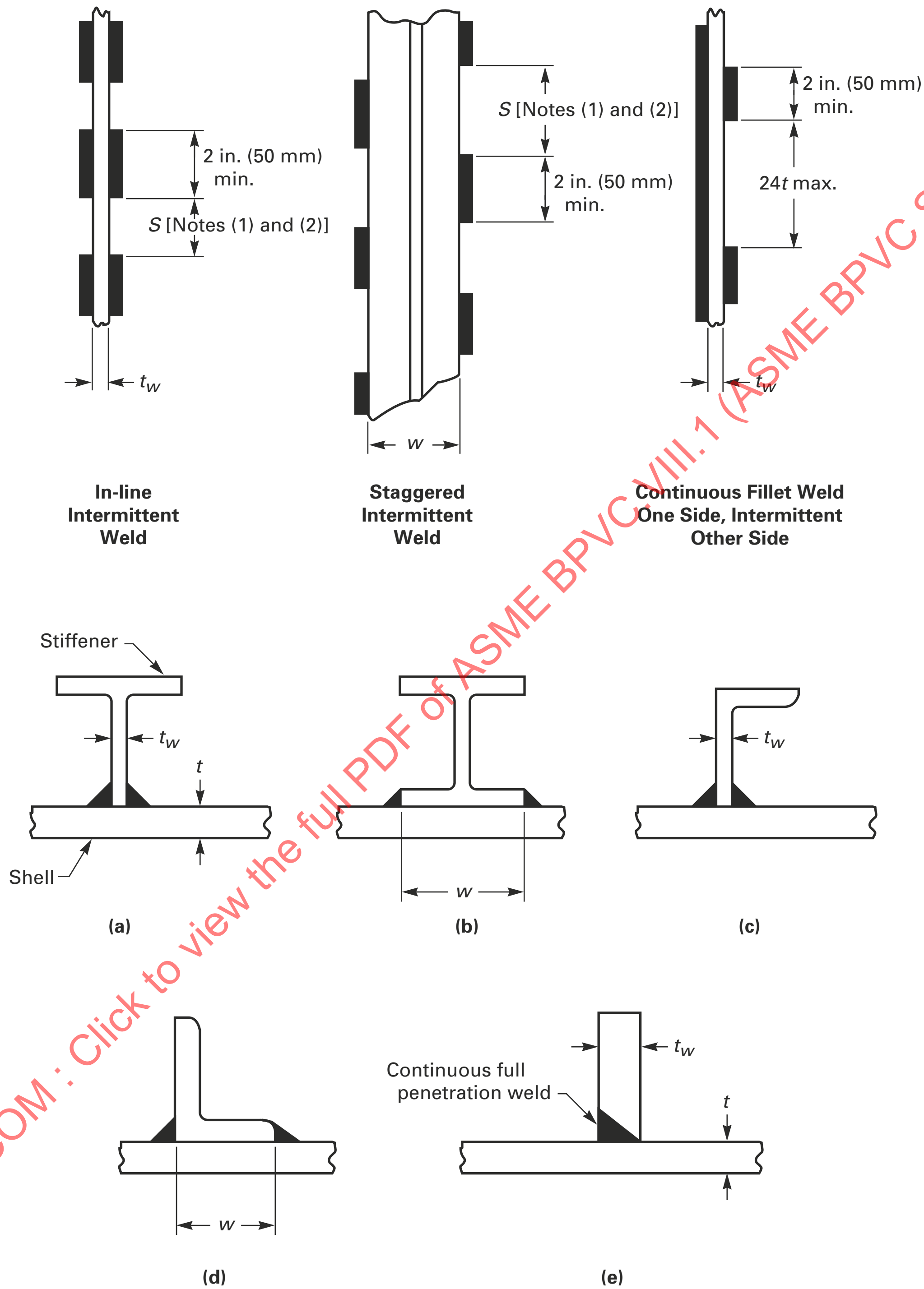
r = inside knuckle radius

S = maximum allowable stress value in tension as given in the tables referenced in UG-23, except as limited in UG-24 and (d) below.

t = minimum required thickness of head after forming

t_s = minimum specified thickness of head after forming, in. (mm). t_s shall be $\geq t$

Figure UG-30
Some Acceptable Methods of Attaching Stiffening Rings



NOTES:
(1) For external stiffeners, $S \leq 8t$.
(2) For internal stiffeners, $S \leq 12t$.

α = one-half of the included (apex) angle of the cone at the centerline of the head (see Mandatory Appendix 1, Figure 1-4)

(c) Ellipsoidal Heads With $t_s/L \geq 0.002$. The required thickness of a dished head of semiellipsoidal form, in which half the minor axis (inside depth of the head minus the skirt) equals one-fourth of the inside diameter of the head skirt, shall be determined by

$$t = \frac{PD}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{D + 0.2t} \tag{1}$$

NOTE: For ellipsoidal heads with $t_s/L < 0.002$, the rules of Mandatory Appendix 1, 1-4(f) shall also be met.

An acceptable approximation of a 2:1 ellipsoidal head is one with a knuckle radius of $0.17D$ and a spherical radius of $0.90D$.

(d) Torispherical Heads With $t_s/L \geq 0.002$. The required thickness of a torispherical head for the case in which the knuckle radius is 6% of the inside crown radius and the inside crown radius equals the outside diameter of the skirt [see (i)] shall be determined by

$$t = \frac{0.885PL}{SE - 0.1P} \quad \text{or} \quad P = \frac{SEt}{0.885L + 0.1t} \tag{2}$$

NOTE: For torispherical heads with $t_s/L < 0.002$, the rules of Mandatory Appendix 1, 1-4(f) shall also be met.

Torispherical heads made of materials having a specified minimum tensile strength exceeding 70,000 psi (485 MPa) shall be designed using a value of S equal to 20,000 psi (138 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material (see UG-23).

(e) Hemispherical Heads. When the thickness of a hemispherical head does not exceed $0.356L$, or P does not exceed $0.665SE$, the following formulas shall apply:

$$t = \frac{PL}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{L + 0.2t} \tag{3}$$

(f) Conical Heads and Sections (Without Transition Knuckle). The required thickness of conical heads or conical shell sections that have a half apex-angle α not greater than 30 deg shall be determined by

$$t = \frac{PD}{2\cos\alpha\left(SE - 0.6P\right)} \quad \text{or} \quad P = \frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha} \tag{4}$$

A reinforcing ring shall be provided when required by the rule in Mandatory Appendix 1, 1-5(d) and 1-5(e).

Conical heads or sections having a half apex-angle α greater than 30 deg without a transition knuckle shall comply with eq. (4) and Mandatory Appendix 1, 1-5(g).

(g) Toriconical Heads and Sections. The required thickness of the conical portion of a toriconical head or section, in which the knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness, shall be determined by eq. (f)(4) in (f) above, using D_i in place of D.

The required thickness of the knuckle shall be determined by Mandatory Appendix 1, eq. 1-4(d)(3) in which

$$L = \frac{D_i}{2\cos\alpha}$$

Toriconical heads or sections may be used when the angle $\alpha \leq 30$ deg and are mandatory for conical head designs when the angle α exceeds 30 deg, unless the design complies with Mandatory Appendix 1, 1-5(g).

(h) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of this paragraph, it shall be stayed as a flat surface according to the rules of UG-47 for braced and stayed flat plates.

(i) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than 3 times the head thickness.

(j) A dished head with a reversed skirt may be used in a pressure vessel, provided the maximum allowable working pressure for the head is established in accordance with the requirements of UG-101.

(k) All formed heads, thicker than the shell and concave to pressure, intended for butt-welded attachment, shall have a skirt length sufficient to meet the requirements of Figure UW-13.1, when a tapered transition is required. All formed heads concave to pressure and intended for butt-welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same inside diameter.

(l) Heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints in Part UB.

(m) Any taper at a welded joint within a formed head shall be in accordance with UW-9. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of UW-13 for the respective type of joint shown therein.

(n) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by eq. UG-34(c)(2)(1), using $C = 0.25$.

(o) Openings in formed heads under internal pressure shall comply with the requirements of UG-36 through UG-46.

(p) A stayed jacket that completely covers a formed inner head or any of the types included in this paragraph shall also meet the requirements of UG-47(c).

(25) UG-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

(a) General. The required thickness at the thinnest point after forming[22] of ellipsoidal, torispherical, hemispherical, toriconical, and conical heads and conical segments under pressure on the convex side (minus heads) shall be computed by the appropriate formulas given in this paragraph (see UG-16). Heads with bolting flanges shall meet the requirements of UG-35.1. In addition, provisions shall be made for any other loading given in UG-22. The required thickness for heads due to pressure on the convex side shall be determined as follows.

(1) For ellipsoidal and torispherical heads, the required thickness shall be computed by the appropriate procedure given in (d) or (e) below.

(2) For hemispherical heads, the required thickness shall be determined by the rules given in (c) below.

(3) For conical and toriconical heads and conical sections, the required thickness shall be determined by the rules given in (f) below.

(b) Nomenclature. The nomenclature defined below is used in this paragraph. Mandatory Appendix 1, Figure 1-4 shows principal dimensions of typical heads.

A, B, E, and P are as defined in UG-28(b)

D_o = outside diameter of the head skirt

$D_o/2h_o$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the outside diameter of the head skirt divided by twice the outside height of the head (see Table UG-33.1)

D_L = outside diameter at large end of conical section under consideration

D_s = outside diameter at small end of conical section under consideration

D_{ss} = outside diameter at small end of conical section under consideration

h_o = one-half of the length of the outside minor axis of the ellipsoidal head, or the outside height of the ellipsoidal head measured from the tangent line (head-bend line)

K_o = factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table UG-33.1)

L_c = axial length of cone or conical section between lines of support (see Figure UG-33.1).

L_e = equivalent length of conical head or Section between lines of support [see (g)]

R_o = for hemispherical heads, the outside radius
= for ellipsoidal heads, the equivalent outside spherical radius taken as K_oD_o
= for torispherical heads, the outside radius of the crown portion of the head

t = minimum required thickness of head after forming, in. (mm)

t_e = effective thickness of conical section
= $t \cos \alpha$

α = one-half the apex angle in conical heads and sections, deg

(c) Hemispherical Heads. The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in UG-28(d) for determining the thickness for a spherical shell.

(d) Ellipsoidal Heads. The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

Step 1. Assume a value for t and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R_o/t}$$

Step 2. Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in UG-28(d), Steps 2 through 6.

(e) Torispherical Heads. The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for R_o.

(f) Conical Heads and Sections. When the cone-to-cylinder junction is not a line-of-support, the required thickness of a conical head or section under pressure on the convex side, either seamless or of built-up construction with butt joints shall not be less than the required thickness of the adjacent cylindrical shell and, when a knuckle is not provided, the reinforcement requirement of Mandatory Appendix 1, 1-8 shall be satisfied (see Figure UG-28.1). When the cone-to-cylinder junction is a line-of-support, the required thickness shall be determined in accordance with the following subparagraphs. This procedure shall also apply to cone sections between lines of support as shown in Figure UG-33.1, sketch (b).

(1) When α is equal to or less than 60 deg:

(-a) cones having D_L/t_e values ≥10:

Step 1. Assume a value for t_e and determine the ratios L_e/D_L and D_L/t_e.

Step 2. Enter Section II, Part D, Subpart 3, Figure G at a value of L/D_o equivalent to the value of L_e/D_L determined in Step 1. For values of L_e/D_L greater than 50, enter the chart at a value of L_e/D_L = 50.

Step 3. Move horizontally to the line for the value of D_o/t equivalent to the value of D_L/t_e determined in Step 1. Interpolation may be made for intermediate values of D_L/t_e; extrapolation is not permitted. From this point of intersection move vertically downwards to determine the value of factor A.

Table UG-33.1
Values of Spherical Radius Factor K_o for Ellipsoidal Head With Pressure on Convex Side

$D_o/2h_o$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_o	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

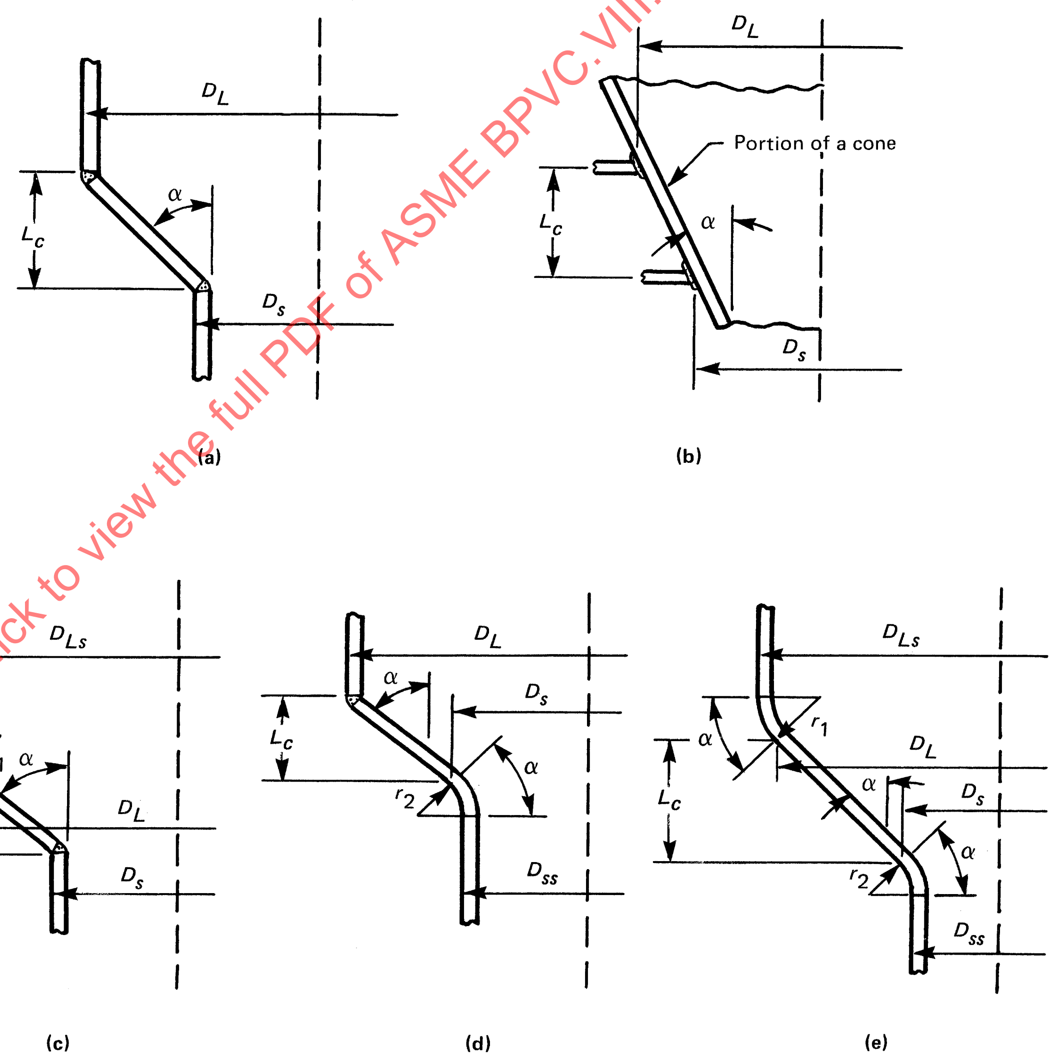
GENERAL NOTE: Interpolation permitted for intermediate values.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

Figure UG-33.1
Length L_c of Some Typical Conical Sections for External Pressure (25)



Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_L/t_e)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_L/t_e)}$$

Step 8. Compare the calculated value of P_a obtained in Step 6 or Step 7 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P.

Step 9. Provide adequate moment of inertia and reinforcement at the cone-to-cylinder junction in accordance with Mandatory Appendix 1, 1-8. For a junction with a knuckle, the reinforcement calculation is not required, and the moment of inertia calculation may be performed either by considering the presence of the knuckle or by assuming the knuckle is not present whereby the cone is assumed to intersect the adjacent cylinder.

(-b) cones having D_L/t_e values <10:

Step 1. Using the same procedure as given in (-a) above, obtain the value of B. For values of D_L/t_e less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_L/t_e)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_L/t_e)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_L/t_e}\left[1 - \frac{1}{D_L/t_e}\right]$$

where

S = the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable table referenced by UG-23, or 0.9 times the yield strength of the material at design temperature

Values of yield strength are obtained from the applicable external pressure chart as follows.

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

Step 4. The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

Step 5. Provide adequate moment of inertia and reinforcement at the cone-to-cylinder junction in accordance with Mandatory Appendix 1, 1-8. For a junction with a knuckle, the reinforcement calculation is not required, and the moment of inertia calculation may be performed either by considering the presence of the knuckle or by assuming the knuckle is not present whereby the cone is assumed to intersect the adjacent cylinder.

(2) When α of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest diameter of the cone (see UG-34).

(3) The thickness of an eccentric cone shall be taken as the greater of the two thicknesses obtained using both the smallest and largest α in the calculations.

(g) The required thickness of a conical part of a toriconical head or conical section having pressure on the convex side, either seamless or of built-up construction with butt joints within the conical part of a toriconical head or conical section, shall not be less than that determined from (f) above with the exception that L_e shall be determined as follows:

(1) For sketches (a) and (b) in Figure UG-33.1,

$$L_e = (L_c/2)(1 + D_s/D_L)$$

(2) For sketch (c) in Figure UG-33.1,

$$L_e = r_1 \sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_{Ls}}\right)$$

(3) For sketch (d) in Figure UG-33.1,

$$L_e = r_2 \frac{D_{ss}}{D_L} \sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_L}\right)$$

(4) For sketch (e) in Figure UG-33.1,

$$L_e = \left(r_1 + r_2 \frac{D_{ss}}{D_{Ls}}\right)\sin\alpha + \frac{L_c}{2}\frac{(D_L + D_s)}{D_{Ls}}$$

(h) When lap joints are used in formed head construction or for longitudinal joints in a conical head under external pressure, the thickness shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(i) The required length of skirt on heads convex to pressure shall comply with the provisions of UG-32(k) and UG-32(l) for heads concave to pressure.

(j) Openings in heads convex to pressure shall comply with the requirements of UG-36 through UG-46.

(25) UG-34 UNSTAYED FLAT HEADS AND COVERS

(a) The minimum thickness of unstayed flat heads, cover plates and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular[24] heads and covers. Some acceptable types of flat heads and covers are shown in Figure UG-34. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

(b) The symbols used in this paragraph and in Figure UG-34 are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in (d) below, dimensionless
D = long span of noncircular heads or covers measured perpendicular to short span
d = diameter, or short span, measured as indicated in Figure UG-34
E = joint efficiency, from Table UW-12, of any Category A weld as defined in UW-3(a)
h_G = gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction, as shown in Mandatory Appendix 2, Table 2-5.2
K = influence coefficient
= 0.2 in. for Customary units
= 5 mm for SI units
L = perimeter of noncircular bolted head measured along the centers of the bolt holes
m = the ratio t_r/t_s, dimensionless
P = internal design pressure (see UG-21)
r = inside corner radius on a head formed by flanging or forging
S = maximum allowable stress value in tension from applicable table of stress values referenced by UG-23
t = minimum required thickness of flat head or cover
t_1 = throat dimension of the closure weld, as indicated in Figure UG-34, sketch (r)
t_f = nominal thickness of the flange on a forged head, at the large end, as indicated in Figure UG-34, sketch (b)
t_h = nominal thickness of flat head or cover
t_r = required thickness of seamless shell, for pressure
t_s = nominal thickness of shell
t_w = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Figure UG-34, sketch (g)
W = design bolt load for the operating condition and the gasket seating condition for circular heads for Mandatory Appendix 2
Y = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Figure UG-34, sketches (a) and (c), in. (mm)
Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span, as given in (c) below, dimensionless

(c) The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements.[25]

(1) Circular blind flanges conforming to any of the flange standards listed in Table U-3 and further limited in UG-44(a) shall be acceptable for the diameters and pressure–temperature ratings in the respective standard when the blind flange is of the types shown in Figure UG-34, sketches (j) and (k).

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE} \qquad (1)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3} \qquad (2)$$

When using eq. (2), the thickness t shall be calculated for both operating conditions and gasket seating, and the greater of the two values shall be used. For operating conditions, the value of P shall be the design pressure, and the values of S at the design temperature and W from Mandatory Appendix 2, eq. 2-5(e)(4) shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from Mandatory Appendix 2, eq. 2-5(e)(5) shall be used.

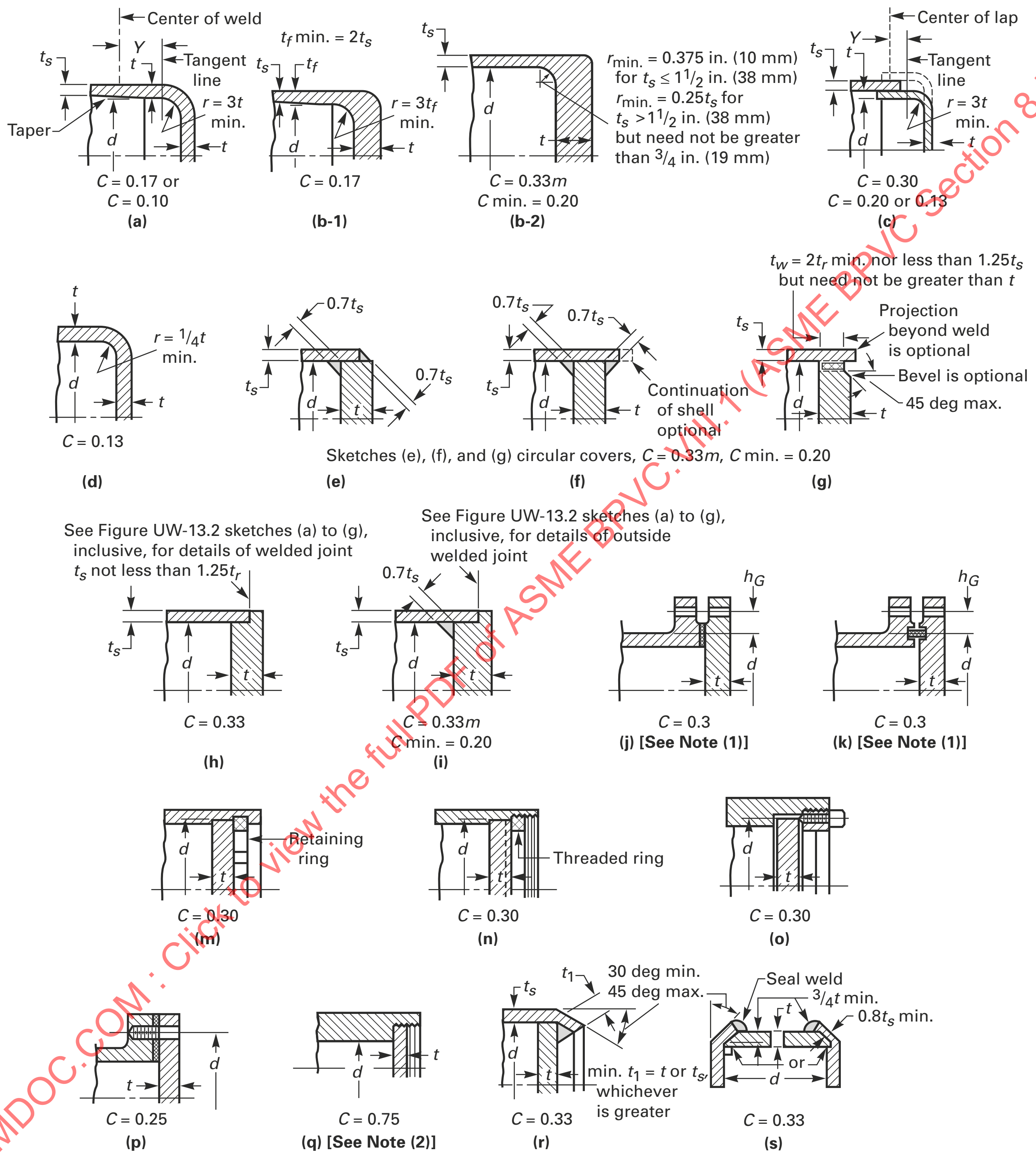
(3) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE} \qquad (3)$$

where

$$Z = 3.4 - \frac{2.4d}{D} \qquad (4)$$

Figure UG-34
Some Acceptable Types of Unstayed Flat Heads and Covers



GENERAL NOTE: The above sketches are diagrammatic only. Other designs that meet the requirements of UG-34 are acceptable.

NOTES:
(1) Use UG-34(c)(2) eq. (2) or UG-34(c)(3) eq. (5).
(2) When pipe threads are used, see Table UG-43.

with the limitation that Z need not be greater than two and one-half (2.5).

Equation (3) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [see Figure UG-34, sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE + 6Wh_G/SELd^2} \quad (5)$$

When using eq. (5), the thickness t shall be calculated in the same way as specified above for eq. (2)(2).

(d) For the types of construction shown in Figure UG-34, the minimum values of C to be used in eqs. (c)(2)(1), (c)(2)(2), (c)(3)(3), and (c)(3)(5) are:

(1) Sketch (a). C = 0.17 for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange, and where the welding meets all the requirements for circumferential joints given in Part UW.

C = 0.10 for circular heads, when the flange length for heads of the above design is not less than

$$Y = \left(1.1 - 0.8\frac{t_s^2}{t_h^2}\right)\sqrt{dt_h} \quad (6)$$

C = 0.10 for circular heads, when the flange length Y is less than the requirements in eq. (6) but the shell thickness is not less than

$$t_s = 1.12t_h\sqrt{1.1 - Y/\sqrt{dt_h}} \quad (7)$$

for a length of at least $2\sqrt{dt_s}$.

When C = 0.10 is used, the taper shall be at least 1:3.

(2) Sketch (b-1). C = 0.17 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in Part UW.

(3) Sketch (b-2). C = 0.33m but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than the following:

$$r_{min} = 0.375 \text{ in. } (10 \text{ mm}) \text{ for } t_s \leq 1^1\!/_2 \text{ in. } (38 \text{ mm})$$

$$r_{min} = 0.25\, t_s \text{ for } t_s > 1^1\!/_2 \text{ in. } (38 \text{ mm}) \text{ but need not be greater than } {}^3\!/_4 \text{ in. } (19 \text{ mm})$$

The welding shall meet all the requirements for circumferential joints given in Part UW.

(4) Sketch (c). C = 0.13 for circular heads lap welded or brazed to the shell with corner radius not less than 3t and Y not less than required by eq. (1)(6) and the requirements of UW-13 are met.

C = 0.20 for circular and noncircular lap welded or brazed construction as above, but with no special requirement with regard to Y.

C = 0.30 for circular flanged plates screwed over the end of the vessel, with inside corner radius not less than 3t, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on the allowable stress values in UG-23 and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

(5) Sketch (d). C = 0.13 for integral flat circular heads when the dimension d does not exceed 24 in. (600 mm), the ratio of thickness of the head to the dimension d is not less than 0.05 or greater than 0.25, the head thickness t_h is not less than the shell thickness t_s, the inside corner radius is not less than 0.25t, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(6) Sketches (e), (f), and (g). C = 0.33m but not less than 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least 0.7t_s. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

C = 0.33 for noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least 0.7t_s. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

(7) Sketch (h). C = 0.33 for circular plates welded to the end of the shell when t_s is at least 1.25t_r and the weld details conform to the requirements of UW-13(e) and Figure UW-13.2, sketches (a) to (g) inclusive. See also UG-93.4.

(8) Sketch (i). C = 0.33m but not less than 0.20 for circular plates if an inside fillet weld with minimum throat thickness of 0.7t_s is used and the details of the outside weld conform to the requirements of UW-13(e) and Figure UW-13.2, sketches (a) to (g) inclusive, in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b. See also UG-93.4.

(9) Sketches (j) and (k). C = 0.3 for circular and noncircular heads and covers bolted to the vessel as indicated in the figures. Note that eq. (c)(2)(2) or (c)(3)(5) shall be used because of the extra moment applied to the cover by the bolting.

When the cover plate is grooved for a peripheral gasket, as shown in sketch (k), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than

$$d\sqrt{1.9Wh_G/Sd^3}$$

for circular heads and covers, nor less than

$$d\sqrt{6Wh_G/SLd^2}$$

for noncircular heads and covers.

(10) Sketches (m), (n), and (o). C = 0.3 for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are designed using the allowable stress values in UG-23. Seal welding may be used, if desired.

(11) Sketch (p). C = 0.25 for circular and noncircular covers bolted with a full-face gasket, to shells, flanges or side plates.

(12) Sketch (q). C = 0.75 for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 12 in. (300 mm); or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 12 in. (300 mm); and when the design of the threaded joint, against failure by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion, is based on the allowable stress values in UG-23. If a tapered pipe thread is used, the requirements of Table UG-43 shall also be met. Seal welding may be used, if desired.

(13) Sketch (r). C = 0.33 for circular plates having a dimension d not exceeding 18 in. (450 mm) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg, but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater.

(14) Sketch (s). C = 0.33 for circular beveled plates having a diameter d not exceeding 18 in. (450 mm), inserted into a vessel, the end of which is crimped over at least 30 deg, but not more than 45 deg, and when the undercutting for seating leaves at least 80% of the shell thickness. The beveling shall be not less than 75% of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio t_s/d shall be not less than the ratio P/S nor less than 0.05. The maximum allowable pressure for this construction shall not exceed $P = KS/d$.

This construction is not permissible if machined from rolled plate.

UG-35 OTHER TYPES OF CLOSURES

UG-35.1 Dished Covers

Requirements for design of dished heads with bolting flanges are given in 1-6.

UG-35.2 Quick-Actuating Closures (25)

(a) Quick-actuating closures are closures that are operated by an action that releases all holding elements.

(b) Design requirements, additional definitions, and recommendations for quick-actuating closures can be found in Section VIII, Division 2, 4.8 and shall be used in accordance with UG-16(a) and Mandatory Appendix 46.

(c) Table UG-35.2-1 lists the new locations for all requirements formerly located in this Division.

UG-35.3 Quick-Opening Closures (25)

(a) Quick-opening closures are closures other than

(1) bolted flange joints as described in UG-44(a)

(2) bolted flange joints meeting the requirements of Mandatory Appendix 2

(3) bolted head joints meeting the requirements of Mandatory Appendix 1, 1-6

(4) quick-actuating closures as described in UG-35.2

Table UG-35.2-1 Paragraph Cross-Reference List (25)

2023 Division 1 Designator, Topic	Division 2
UG-35.2(a), Definitions	4.8.2
UG-35.2(b), General	4.8.3, 4.8.5
UG-35.2(c), Specific design requirements	4.8.5
UG-35.2(d), Alternative designs for manually operated closures	4.8.5(g), 4.8.5(h)
UG-35.3(a), Definitions	4.8.2
UG-35.3(b), General	4.8.3, 4.8.4
UG-35.3(c), Specific design requirements	4.8.4
Nonmandatory Appendix FF	Annex 4-B

(5) clamp connections meeting the requirements of Mandatory Appendix 24

(6) closures with multiple, manually operated swing bolts

(b) Additional definitions, rules, and recommendations for quick-opening closures can be found in Section VIII, Division 2, 4.8 and shall be used in accordance with UG-16(a) and Mandatory Appendix 46.

(c) Table UG-35.2-1 lists the new locations for all requirements formerly located in this Division.

OPENINGS AND REINFORCEMENTS[26]

UG-36 OPENINGS IN PRESSURE VESSELS

(a) Shape of Opening [27]

(1) Openings in cylindrical or conical portions of vessels, or in formed heads, shall preferably be circular, elliptical, or obround.[28] When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(2) Openings may be of other shapes than those given in (1) above, and all corners shall be provided with a suitable radius. These openings shall be designed in accordance with U-2(g).

(b) Size of Openings

(1) Properly reinforced openings in cylindrical and conical shells are not limited as to size except with the following provisions for design. The rules in UG-36 through UG-43 apply to openings not exceeding the following: for vessels 60 in. (1 520 mm) inside diameter and less, one-half the vessel diameter, but not to exceed 20 in. (510 mm); for vessels over 60 in. (1 520 mm) inside diameter, one-third the vessel diameter, but not to exceed 40 in. (1 020 mm). (For conical shells, the inside shell diameter as used above is the cone diameter at the center of the opening.) For openings exceeding these limits, supplemental rules of Mandatory Appendix 1, 1-7 shall be satisfied in addition to the rules of this paragraph.

(2) Properly reinforced openings in formed heads and spherical shells are not limited in size. For an opening in an end closure, which is larger than one-half the inside diameter of the shell, one of the following alternatives to reinforcement may also be used:

(-a) a conical section as shown in Figure UG-36, sketch (a);

(-b) a cone with a knuckle radius at the large end as shown in Figure UG-36, sketch (b);

(-c) a reverse curve section as shown in Figure UG-36, sketches (c) and (d); or

(-d) using a flare radius at the small end as shown in Figure UG-33.1, sketch (d).

The design shall comply with all the requirements of the rules for reducer sections [see (e) below] insofar as these rules are applicable.

(c) Strength and Design of Finished Openings

(1) All references to dimensions in this and succeeding paragraphs apply to the finished construction after deduction has been made for material added as corrosion allowance. For design purposes, no metal added as corrosion allowance may be considered as reinforcement. The finished opening diameter is the diameter d as defined in UG-37 and in Figure UG-40.

(2) See below.

(-a) Openings in cylindrical or conical shells, or formed heads shall be reinforced to satisfy the requirements in UG-37 except as given in (3) below.

(-b) Openings in flat heads shall be reinforced as required by UG-39.

(3) Openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:

(-a) welded, brazed, and flued connections meeting the applicable rules and with a finished opening not larger than:

(-1) $3^1/_2$ in. (89 mm) diameter — in vessel shells or heads with a required minimum thickness of $^3/_8$ in. (10 mm) or less;

(-2) $2^3/_8$ in. (60 mm) diameter — in vessel shells or heads over a required minimum thickness of $^3/_8$ in. (10 mm);

(-b) threaded, studded, or expanded connections in which the hole cut in the shell or head is not greater than $2^3/_8$ in. (60 mm) diameter;

(-c) no two isolated unreinforced openings, in accordance with (-a) or (-b) above, shall have their centers closer to each other than the sum of their diameters;

(-d) no two unreinforced openings, in a cluster of three or more unreinforced openings in accordance with (-a) or (-b) above, shall have their centers closer to each other than the following:

for cylindrical or conical shells,

$$\left(1 + 1.5\cos\theta\right)\left(d_1 + d_2\right);$$

for doubly curved shells and formed or flat heads,

$$2.5\left(d_1 + d_2\right)$$

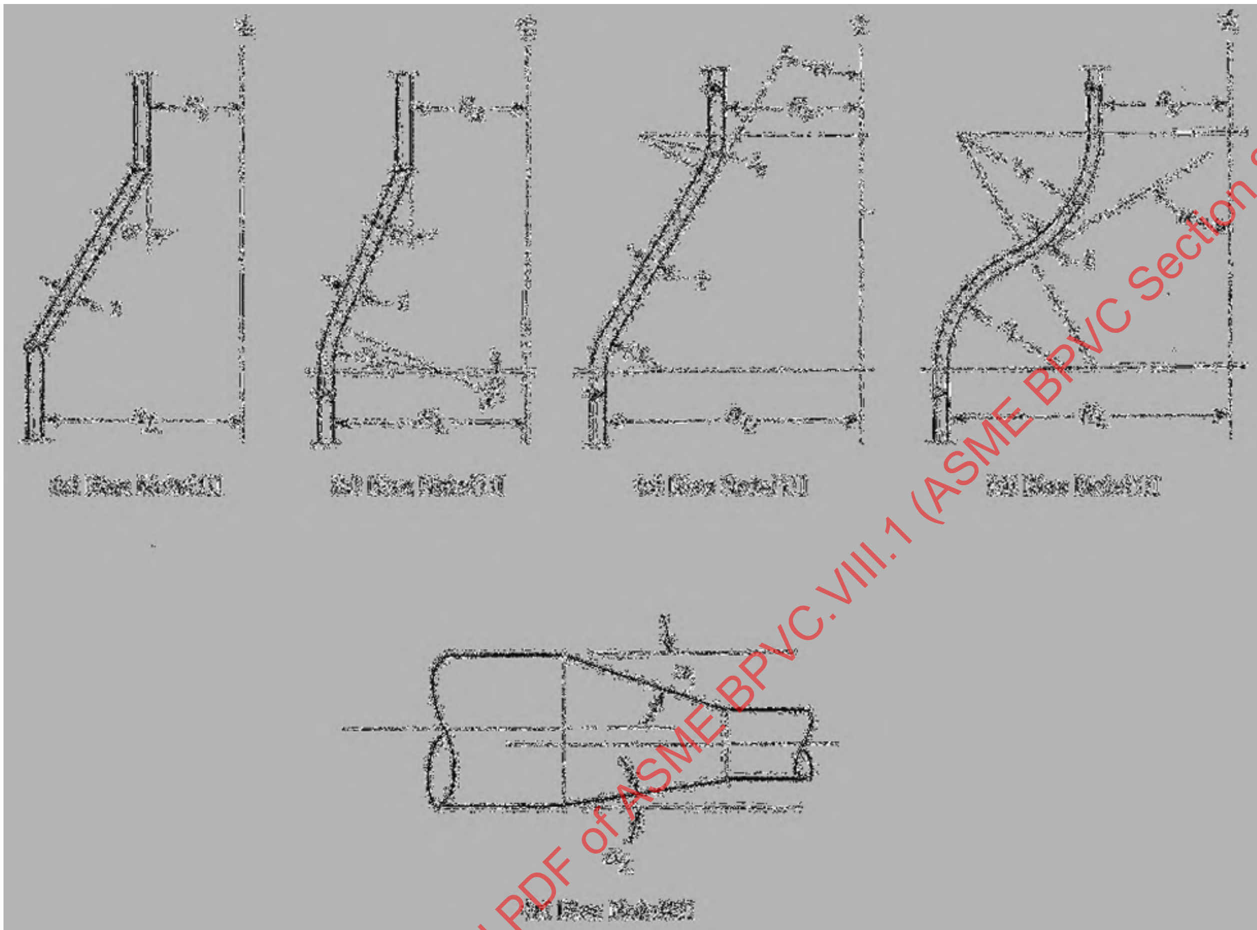
where

d_1, d_2 = the finished diameter of the two adjacent openings

θ = the angle between the line connecting the center of the openings and the longitudinal axis of the shell

The centerline of an unreinforced opening as defined in (-a) and (-b) above shall not be closer than its finished diameter to any material used for reinforcement of an adjacent reinforced opening.

Figure UG-36
Large Head Openings — Reverse-Curve and Conical Shell-Reducer Sections



NOTES:
(1) r_L shall not be less than the greater of $0.12(R_L + t)$ or $3t$: r_s has no dimensional requirement.
(2) $\alpha_1 > \alpha_2$; therefore, use α_1 in design equations.

(d) Openings Through Welded Joints. Additional provisions governing openings through welded joints are given in UW-14.

(e) Reducer Sections Under Internal Pressure

(1) The equations and rules of this paragraph apply to concentric reducer sections wherein all the longitudinal loads are transmitted wholly through the shell of the reducer. Where loads are transmitted in part or as a whole by other elements, e.g., inner shells, stays, or tubes, the rules of this paragraph do not apply.

(2) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable formula. In addition, provisions shall be made for any of the other loadings listed in UG-22, where such loadings are expected.

(3) The symbols defined in either UG-32(b) or below are used in this paragraph (see Figure UG-36).

t = minimum required thickness of the considered element of a reducer after forming
R_L = inside radius of larger cylinder
R_s = inside radius of smaller cylinder
r_L = inside radius of knuckle at larger cylinder
r_s = radius to the inside surface of flare at the small end
α = one-half of the included (apex) angle of a conical element

(4) Elements of a Reducer. A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of this paragraph are met.

(-a) Conical Shell Section. The required thickness of a conical shell section, or the allowable working pressure for such a section of given thickness, shall be determined by the equations given in UG-32(f).

(-b) Knuckle Tangent to the Larger Cylinder. Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of the appropriate equations and provisions of UG-32.

(5) Combination of Elements to Form a Reducer. When elements of (4) above, having different thicknesses are combined to form a reducer, the joints including the plate taper required by UW-9(c) shall lie entirely within the limits of the thinner element being joined.

(-a) A reducer may be a simple conical shell section, Figure UG-36, sketch (a), without knuckle, provided the half-apex angle α is not greater than 30 deg, except as provided for in Mandatory Appendix 1, 1-5(g). A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of Mandatory Appendix 1, 1-5.

(-b) A toriconical reducer, Figure UG-36, sketch (b), may be shaped as a portion of a toriconical head, UG-32(g), a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half-apex angle α is not greater than 30 deg, except as provided for in Mandatory Appendix 1, 1-5(g). A reinforcement ring shall be provided at the small end of the conical reducer element when required by the rules in Mandatory Appendix 1, 1-5.

(-c) Reverse curve reducers, Figure UG-36, sketches (c) and (d), may be shaped of elements other than those of (4) above. See U-2(g).

(f) Reducers Under External Pressure. The rules of UG-33(f) shall be followed, where applicable, in the design of reducers under external pressure.

(g) Oblique Conical Shell Sections Under Internal Pressure. A transition section reducer consisting of an oblique conical shell section may be used to join two cylindrical shell sections of different diameters and axes, provided the following requirements are used:

(1) The required thickness shall be determined by the equations given in UG-32(f).

(2) The angle α to be used shall be the largest included angle between the oblique cone and the attached cylindrical section [see Figure UG-36, sketch (e)] and shall not be greater than 30 deg, except as provided for in Mandatory Appendix 1, 1-5(g)

(3) Diametrical dimensions to be used in the design equations shall be measured perpendicular to the axis of the cylinder to which the cone is attached.

(4) A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of Mandatory Appendix 1, 1-5.

UG-37 REINFORCEMENT REQUIRED FOR OPENINGS IN SHELLS AND FORMED HEADS

(a) Nomenclature. The symbols used in this paragraph are defined as follows:

A = total cross-sectional area of reinforcement required in the plane under consideration (see Figure UG-37.1) (includes consideration of nozzle area through shell if $S_n/S_v < 1.0$)

A_1 = area in excess thickness in the vessel wall available for reinforcement (see Figure UG-37.1) (includes consideration of nozzle area through shell if $S_n/S_v < 1.0$)

A_2 = area in excess thickness in the nozzle wall available for reinforcement (see Figure UG-37.1)

A_3 = area available for reinforcement when the nozzle extends inside the vessel wall (see Figure UG-37.1)

A_5 = cross-sectional area of material added as reinforcement (see Figure UG-37.1)

A_{41}, A_{42}, A_{43} = cross-sectional area of various welds available for reinforcement (see Figure UG-37.1)

c = corrosion allowance

D = inside shell diameter

D_p = outside diameter of reinforcing element (actual size of reinforcing element may exceed the limits of reinforcement established by UG-40; however, credit cannot be taken for any material outside these limits)

d = finished diameter of circular opening or finished dimension (chord length at midsurface of thickness excluding excess thickness available for reinforcement) of nonradial opening in the plane under consideration, in. (mm) [see Figures UG-37.1 and UG-40]

E = 1 (see definitions for t_r and t_{rn})

E_1 = 1 when an opening is in the solid plate or in a Category B butt joint; or

= 0.85 when an opening is located in an ERW or autogenously welded pipe or tube. If the ERW or autogenously welded joint is clearly identifiable and it can be shown that the opening does not pass through this weld joint, then E_1 may be determined using the other rules of this paragraph; or

= joint efficiency obtained from Table UW-12 when any part of the opening passes through any other welded joint

F = correction factor that compensates for the variation in internal pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Figure UG-37 may be used for integrally reinforced openings in cylindrical shells and cones. [See UW-16(c)(1).]

f_r = strength reduction factor, not greater than 1.0 [see UG-41(a)]

f_{r1} = S_n/S_v for nozzle wall inserted through the vessel wall
= 1.0 for nozzle wall abutting the vessel wall and for nozzles shown in Figure UG-40, sketch (j), (k), (n), and (o).

f_{r2} = S_n/S_v

f_{r3} = (lesser of S_n or S_p)/S_v

f_{r4} = S_p/S_v

h = distance nozzle projects beyond the inner surface of the vessel wall. (Extension of the nozzle beyond the inside surface of the vessel wall is not limited; however, for reinforcement calculations, credit shall not be taken for material outside the limits of reinforcement established by UG-40.)

K_1 = spherical radius factor (see definition of t_r and Table UG-37)

L = length of projection defining the thickened portion of integral reinforcement of a nozzle neck beyond the outside surface of the vessel wall [see Figure UG-40, sketch (e)]

P = internal design pressure (see UG-21), psi (MPa)

R = inside radius of the shell course under consideration

R_n = inside radius of the nozzle under consideration

S = allowable stress value in tension (see UG-23), psi (MPa). For welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85.

S_n = allowable stress in nozzle, psi (MPa) (see S above)

S_p = allowable stress in reinforcing element (plate), psi (MPa) (see S above)

S_v = allowable stress in vessel, psi (MPa) (see S above)

t = specified vessel wall thickness,[29] (not including forming allowances). For pipe it is the nominal thickness less manufacturing undertolerance allowed in the pipe specification.

t_e = thickness or height of reinforcing element (see Figure UG-40)

t_i = nominal thickness of internal projection of nozzle wall

t_n = nozzle wall thickness.[29] Except for pipe, this is the wall thickness not including forming allowances. For pipe, use the nominal thickness [see UG-16.4(b)].

t_r = required thickness of a seamless shell based on the circumferential stress, or of a formed head, computed by the rules of this Division for the designated pressure, using E = 1, and, for shells fabricated from welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85, except that

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by Mandatory Appendix 1, 1-4(d), using M = 1;

(b) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone;

(c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius K_1D, where D is the shell diameter and K_1 is given by Table UG-37.

t_{rn} = required thickness of a seamless nozzle wall, using E = 1, and, for nozzles fabricated from welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85.

W = total load to be carried by attachment welds (see UG-41)

(b) *General*. The rules in this paragraph apply to all openings other than:

(1) small openings covered by UG-36(c)(3);

(2) openings in flat heads covered by UG-39;

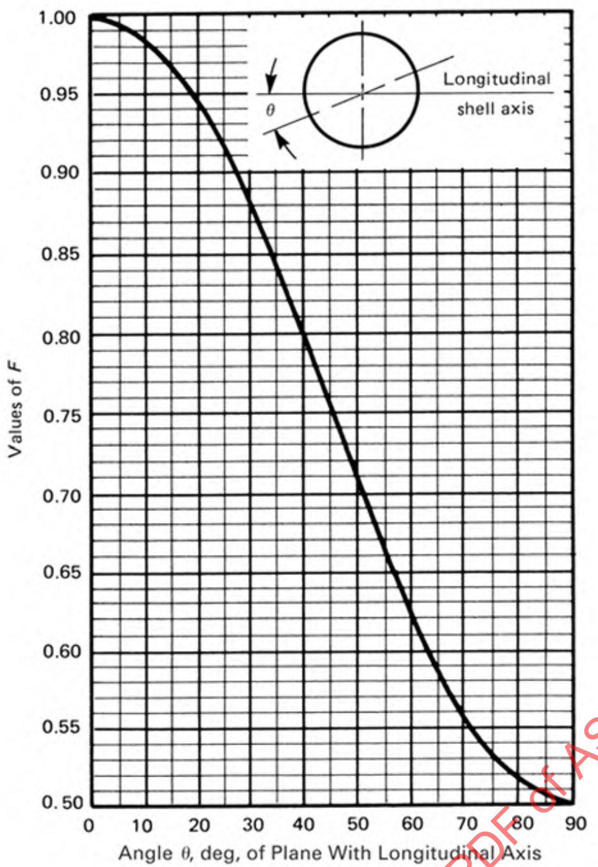
(3) openings designed as reducer sections covered by UG-36(e);

(4) large head openings covered by UG-36(b)(2);

(5) tube holes with ligaments between them conforming to the rules of UG-53.

Reinforcement shall be provided in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface. For a circular opening in a cylindrical shell, the plane containing the

Figure UG-37
Chart for Determining Value of F, as Required in UG-37



axis of the shell is the plane of greatest loading due to pressure. Not less than half the required reinforcement shall be on each side of the centerline of single openings.

(c) Design for Internal Pressure. The total cross-sectional area of reinforcement A required in any given plane through the opening for a shell or formed head under internal pressure shall be not less than

$$A = dt_rF + 2t_nt_rF\left(1 - f_{r1}\right)$$

(d) Design for External Pressure

(1) The reinforcement required for openings in single-walled vessels subject to external pressure need be only 50% of that required in (c) above, where t_r is the wall thickness required by the rules for vessels under external pressure and the value of F shall be 1.0 in all external pressure reinforcement calculations.

(2) The reinforcement required for openings in each shell of a multiple-walled vessel shall comply with (1) above when the shell is subject to external pressure, and with (c) above when the shell is subject to internal pressure, regardless of whether or not there is a common nozzle secured to more than one shell by strength welds.

(e) Design for Alternate Internal and External Pressure. Reinforcement of vessels subject to alternate internal and external pressures shall meet the requirements of (c) above for internal pressure and of (d) above for external pressure.

(f) Details and equations for required area and available area are given in Figure UG-37.1.

(g) Reinforcing plates and saddles of nozzles attached to the outside of a vessel shall be provided with at least one vent hole [maximum diameter $^7/_{16}$ in. (11 mm)] that may be tapped with straight or tapered threads. These vent holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

(h) Segmental reinforcing elements are allowed, provided the individual segments are joined by full penetration butt welds. These butt welds shall comply with all the applicable requirements of Part UW. Each segment of the reinforcing element shall have a vent hole as required by (g). Unless the provisions given below are satisfied, the area A_5 as defined in Figure UG-37.1 shall be multiplied by 0.75. The area A_5 does not require any reduction if one of the following is satisfied:

(1) Each butt weld is radiographed or ultrasonically examined to confirm full penetration, or

(2) For openings in cylinders, the weld is oriented at least 45 deg from the longitudinal axis of the cylinder.

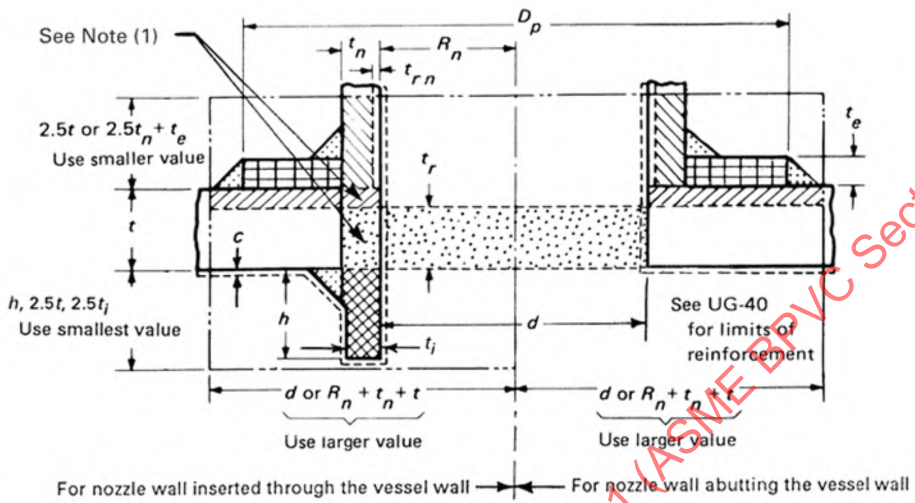
(i) The reinforcement rules in this Division are applicable for internal or external pressure and do not address the requirements for openings under the action of externally applied loadings (such as pipe reactions). When externally applied loadings are to be considered, see U-2(g).

UG-38 FLUED OPENINGS IN SHELLS AND FORMED HEADS

(a) Flued openings in shells and formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in UG-37. The thickness of the flued flange shall also meet the requirements of UG-27 and/or UG-28, as applicable, where L as used in UG-28 is the minimum depth of flange as shown in Figure UG-38. The minimum thickness of the flued flange on a vessel subject to both internal and external pressure shall be the larger of the two thicknesses as determined above.

(b) The minimum depth of flange of a flued in opening exceeding 6 in. (150 mm) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or (t_r + 3 in.) (for SI units, t_r + 75 mm), whichever is less, where t_r is the required shell or head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straightedge to the edge of the flanged opening (see Figure UG-38).

Figure UG-37.1
Nomenclature and Formulas for Reinforced Openings



Without Reinforcing Element

A	$= d\,t_r\,F + 2t_n\,t_r\,F(1 - f_{r1})$	Area required
A_1	$= d(E_1\,t - Ft_r) - 2t_n\,(E_1 t - Ft_r)\,(1 - f_{r1})$ $= 2(t + t_n)(E_1 t - Ft_r) - 2t_n(E_1 t - Ft_r)(1 - f_{r1})$	Area available in shell; use larger value
A_2	$= 5(t_n - t_{rn})\,f_{r2}t$ $= 5(t_n - t_{rn})\,f_{r2}t_n$	Area available in nozzle projecting outward; use smaller value
A_3	$= 5t\,t_i\,f_{r2}$ $= 5t_i\,t_i\,f_{r2}$ $= 2h\,t_i\,f_{r2}$	Area available in inward nozzle; use smallest value
A_{41}	= outward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in outward weld
A_{43}	= inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld

If $A_1 + A_2 + A_3 + A_{41} + A_{43} \geq A$ — Opening is adequately reinforced

If $A_1 + A_2 + A_3 + A_{41} + A_{43} < A$ — Opening is not adequately reinforced so reinforcing elements must be added and/or thicknesses must be increased

With Reinforcing Element Added

A	= same as A, above	Area required
A_1	= same as A_1, above	Area available
A_2	$= 5(t_n - t_{rn})f_{r2}t$ $= 2(t_n - t_{rn})\,(2.5t_n + t_e)f_{r2}$	Area available in nozzle projecting outward; use smaller area
A_3	= same as A_3, above	Area available in inward nozzle
A_{41}	= outward nozzle weld = $(\text{leg})^2 f_{r3}$	Area available in outward weld
A_{42}	= outer element weld = $(\text{leg})^2 f_{r4}$	Area available in outer weld
A_{43}	= inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
A_5	$= (D_p - d - 2t_n)\,t_e\,f_{r4}$ [Note (2)]	Area available in element

If $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 \geq A$ — Opening is adequately reinforced

GENERAL NOTE: This figure illustrates a common nozzle configuration and is not intended to prohibit other configurations permitted by the Code.

NOTES:
(1) Includes consideration of these areas if $S_n/S_v < 1.0$ (both sides of centerline).
(2) This formula is applicable for a rectangular cross-sectional element that falls within the limits of reinforcement.

Table UG-37
Values of Spherical Radius Factor K_1

$D/2h$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_1	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTES:
(a) Equivalent spherical radius = K_1D; $D/2h$ = axis ratio.
(b) For definitions, see Mandatory Appendix 1, 1-4(b).
(c) Interpolation permitted for intermediate values.

(c) There is no minimum depth of flange requirement for flued out openings.

(d) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with UG-46(j).

(25) UG-39 REINFORCEMENT REQUIRED FOR OPENINGS IN FLAT HEADS AND COVERS

(a) General. The rules in this paragraph apply to all openings in flat heads except opening(s) that do not exceed the size and spacing limits in UG-36(c)(3) and do not exceed one-fourth the head diameter or shortest span. Electric immersion heater support plates (see Mandatory Appendix 41, 41-3) may be designed in accordance with the rules of this paragraph or Mandatory Appendix 41.

(b) Single and multiple openings in flat heads that have diameters equal to or less than one-half the head diameter may be reinforced as follows:

(1) Flat heads that have a single opening with a diameter that does not exceed one-half the head diameter or shortest span, as defined in UG-34, shall have a total cross-sectional area of reinforcement for all planes through the center of the opening not less than that given by the formula

$$A = 0.5dt + tt_n\left(1 - f_{r1}\right)$$

where d, t_n, and f_{r1} are defined in UG-37 and t in UG-34.

(2) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced individually as required by (1) above when the spacing between any pair of adjacent openings is equal to or greater than twice the average diameter of the pair.

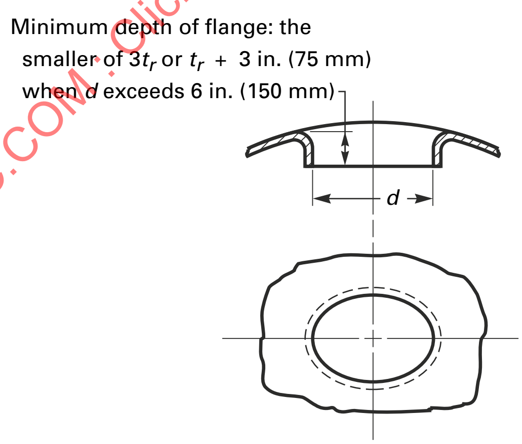
When spacing between adjacent openings is less than twice but equal to or more than $1^1/_4$ the average diameter of the pair, the required reinforcement for each opening in the pair, as determined by (1) above, shall be summed together and then distributed such that 50% of the sum is located between the two openings. Spacings of less than $1^1/_4$ the average diameter of adjacent openings shall be treated by rules of U-2(g).

(3) Referencing Figure UG-39, sketch (a), the ligament between two adjacent openings (U_1, U_2, or U_3) shall not be less than one-quarter of the diameter of the smaller of the two openings in the pair. The radial distance between the inner edge of the opening (U_4, U_5, U_6, or U_7) and the dimension d as shown in Figure UG-34 and Figure UG-39, sketch (a) shall not be less than one-quarter of the diameter of that one opening.

(c) Flat heads that have an opening with a diameter that exceeds one-half the head diameter or shortest span, as defined in UG-34, shall be designed as follows:

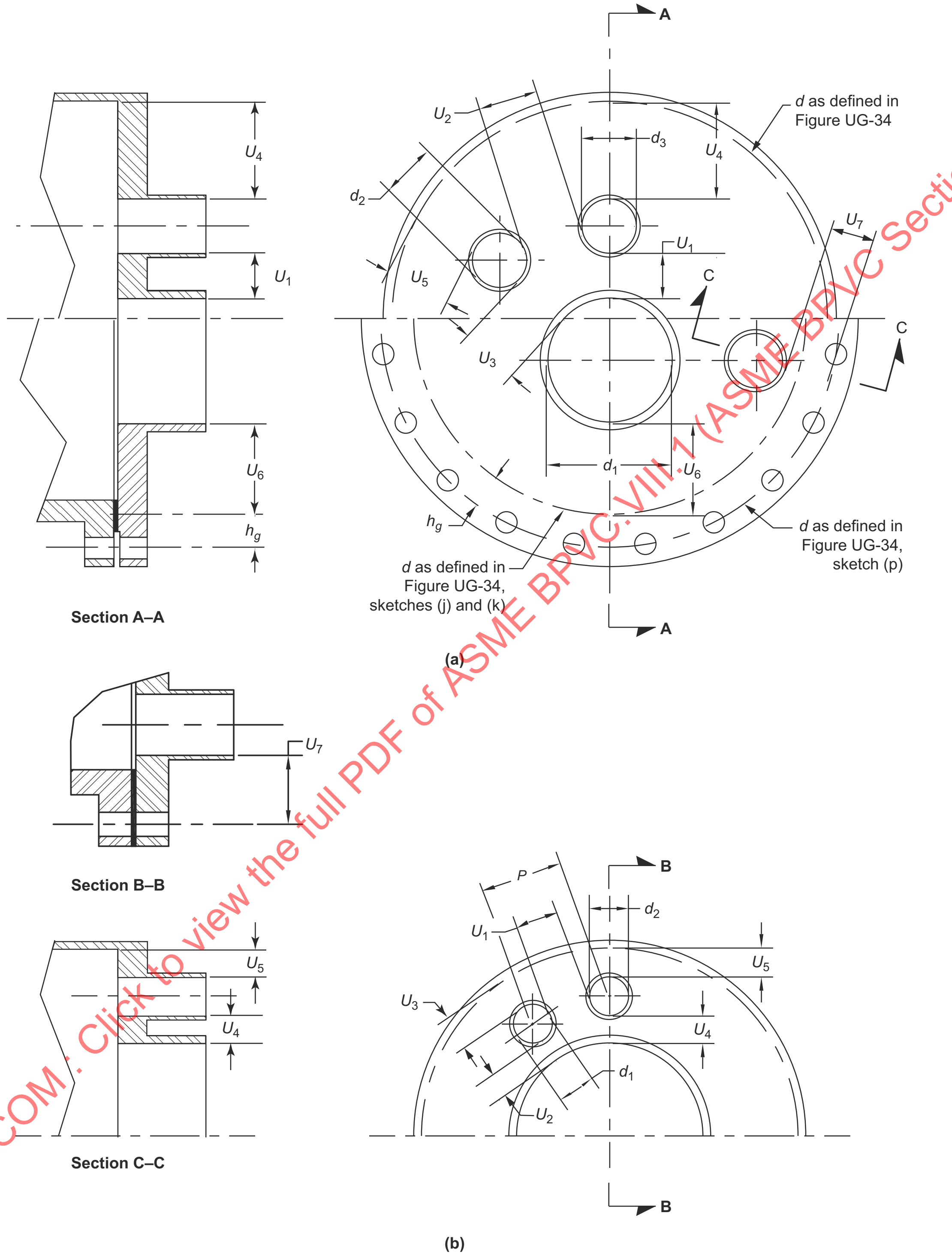
(1) When the opening is a single, circular centrally located opening in a circular flat head, the head shall be designed according to Mandatory Appendix 14 and related factors in Mandatory Appendix 2. The head-to-shell junction may be integral, as shown in Figure UG-34, sketches (a), (b-1), (b-2), (d), and (g). The head may also be attached by a butt weld or a full-penetration corner weld similar to the joints shown in Figure UW-13.2, sketches (a), (b), (c), (d), (e), or (f). The large centrally located opening may have a nozzle that is integrally formed or integrally attached by a full penetration weld or may be plain without an attached nozzle or hub. The head thickness does not have to be calculated by UG-34 rules. The thickness that satisfies all the requirements of Mandatory Appendix 14 meets the requirements of the Code.

Figure UG-38
Minimum Depth for Flange of Flued-In Openings



(25)

Figure UG-39
Openings in Flat Heads and Covers



Legend:

p = spacing, center-to-center, between openings
$U_1, U_2,...$ = ligament width
$(d_1 + d_2)/2$ = average diameter of pair of openings

(2) Opening(s) may be located in the rim space surrounding the central opening. See Figure UG-39, sketch (b). Such openings may be reinforced by area replacement in accordance with the formula in (b)(1) above using as a required head thickness the thickness that satisfies rules of Mandatory Appendix 14. Multiple rim openings shall meet spacing rules of (b)(2) and (b)(3) above. Alternatively, the head thickness that meets the rules of Mandatory Appendix 14 may be increased by multiplying it by the square root of two (1.414) if only a single opening is placed in the rim space or if spacing p between two such openings is twice or more than their average diameter. For spacing less than twice their average diameter, the thickness that satisfies Mandatory Appendix 14 shall be divided by the square root of efficiency factor e, where e is defined in (e)(2) below.

The rim opening(s) shall not be larger in diameter than one-quarter the differences in head diameter less central opening diameter. The minimum ligament width U shall not be less than one-quarter the diameter of the smaller of the two openings in the pair. A minimum ligament width of one-quarter the diameter of the rim opening applies to ligaments designated as U_2, U_4, U_3, and U_5 in Figure UG-39, sketch (b).

(3) When the large opening is any other type than that described in (1) above, there are no specific rules given. Consequently, the requirements of U-2(g) shall be met.

(d) As an alternative to (b)(1) above, the thickness of flat heads and covers with a single opening with a diameter that does not exceed one-half the head diameter may be increased to provide the necessary reinforcement as follows:

(1) In eq. UG-34(c)(2)(1) or eq. UG-34(c)(3)(3), use $2C$ or 0.75 in place of C, whichever is the lesser; except that, for sketches (b-1), (b-2), (e), (f), (g), and (i) of Figure UG-34, use $2C$ or 0.50, whichever is the lesser.

(2) In eq. UG-34(c)(2)(2) or eq. UG-34(c)(3)(5), double the quantity under the square root sign.

(e) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced as follows:

(1) When the spacing between a pair of adjacent openings is equal to or greater than twice the average diameter of the pair, and this is so for all opening pairs, the head thickness may be determined by rules in (d) above.

(2) When the spacing between adjacent openings in a pair is less than twice but equal to or greater than $1\frac{1}{4}$ the average diameter of the pair, the required head thickness shall be that determined by (d) above multiplied by a factor h, where

$$h = \sqrt{0.5 / e}$$

$$e = [(p - d_{ave})/p]_{smallest}$$

where

d_{ave} = average diameter of the same two adjacent openings

e = smallest ligament efficiency of adjacent opening pairs in the head

p = center-to-center spacing of two adjacent openings

(3) Spacings of less than $1\frac{1}{4}$ the average diameter of adjacent openings shall be treated by rules of U-2(g).

(4) In no case shall the width of ligament between two adjacent openings be less than one-quarter the diameter of the smaller of the two openings in the pair.

(5) The width of ligament between the edge of any one opening and the edge of the flat head (such as U_3 or U_5 in Figure UG-39) shall not be less than one-quarter the diameter of that one opening.

UG-40 LIMITS OF REINFORCEMENT

(a) The boundaries of the cross sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal must be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane (see Figure UG-37.1). Figure UG-40 depicts thicknesses t, t_e, and t_n, or t_i and diameter d used in establishing the limits of reinforcement. All dimensions are in the corroded condition; for nomenclature, see UG-37(a).

(b) The limits of reinforcement, measured parallel to the vessel wall, shall be at a distance, on each side of the axis of the opening, equal to the greater of the following:

(1) the diameter d of the finished opening;

(2) the inside radius, R_n, of the nozzle plus the vessel wall thickness t, plus the nozzle wall thickness t_n.

(c) The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the smaller of the following:

(1) $2\frac{1}{2}$ times the vessel wall thickness t;

(2) $2\frac{1}{2}$ times the nozzle wall thickness t_n plus the thickness t_e as defined in Figure UG-40.

(d) Metal within the limits of reinforcement that may be considered to have reinforcing value shall include the following:

(1) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. the area in the vessel wall available as reinforcement is the larger of the values of A_1 given by the equations in Figure UG-37.1.

(2) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside

Figure UG-40
Some Representative Configurations Describing the Reinforcement Dimension t_e and the Opening Dimension d

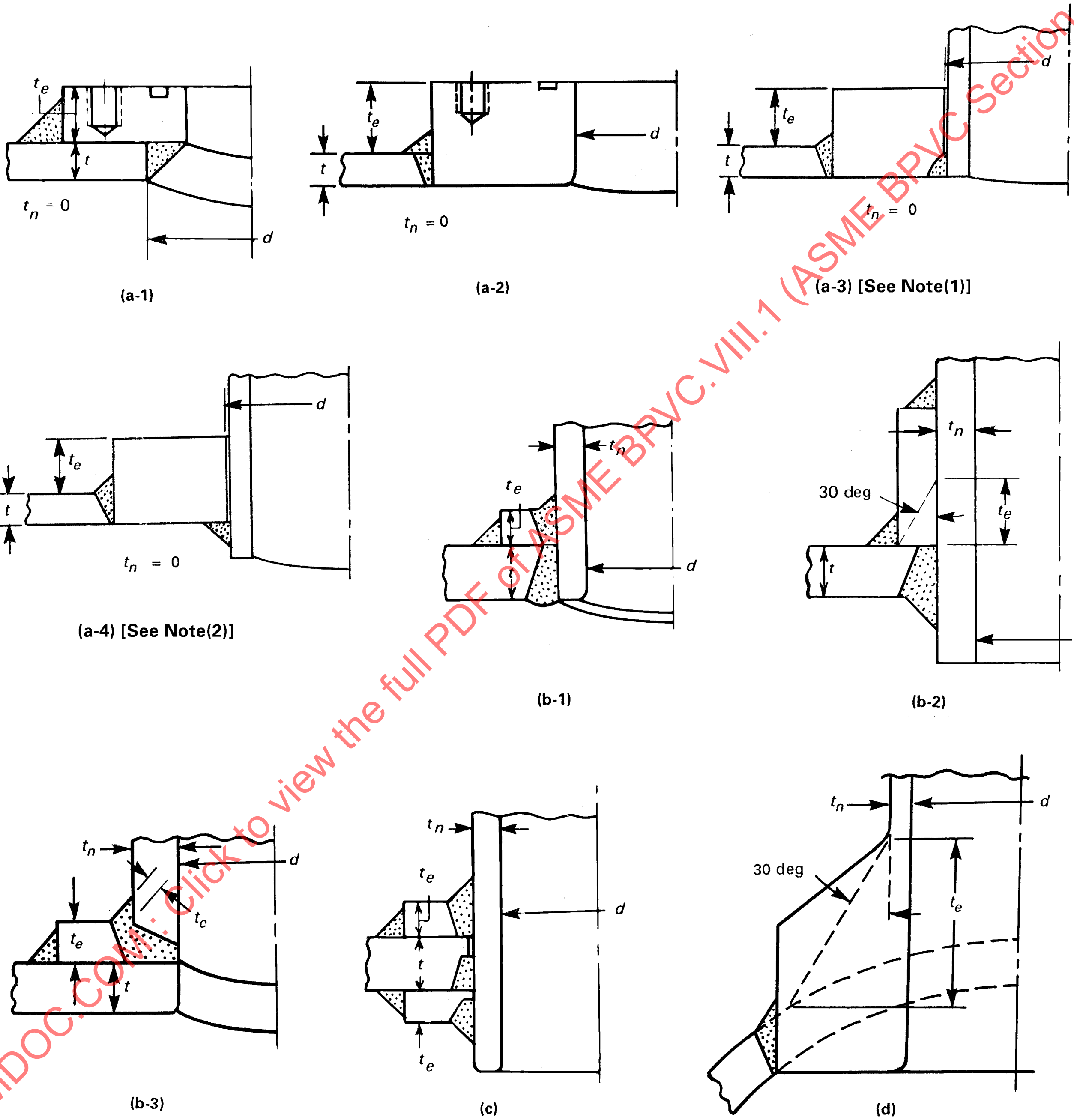
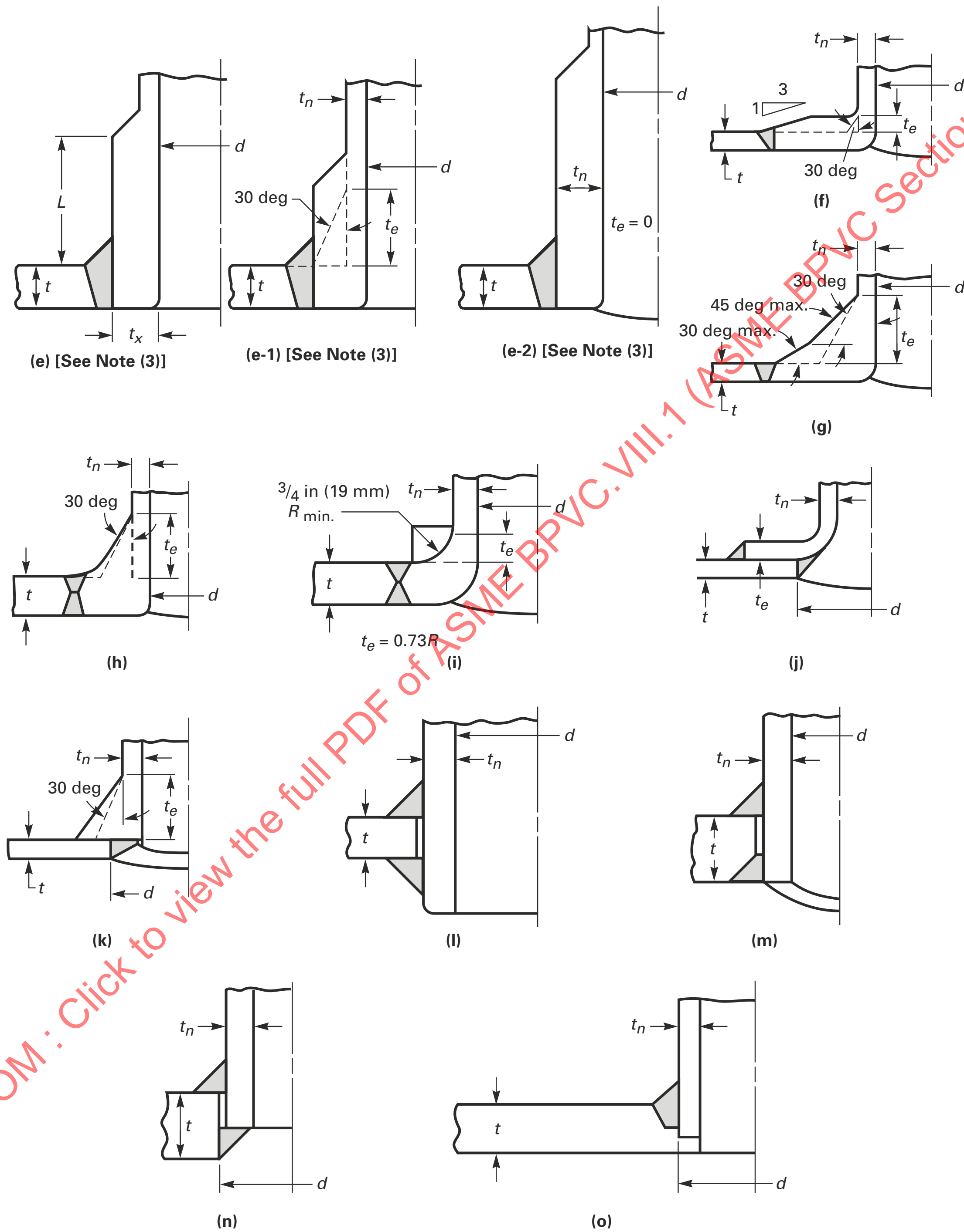


Figure UG-40
Some Representative Configurations Describing the Reinforcement Dimension t_e and the Opening Dimension d (Cont'd)



NOTES:
(1) See Figure UW-16.1, sketch (v-2) for limitations.
(2) See Figure UW-16.1, sketch (w-2) for limitations.
(3) If $L < 2.5t_x$, use sketch (e-1); if $L \geq 2.5t_x$, use sketch (e-2).

the vessel wall. The maximum area in the nozzle wall available as reinforcement is the smaller of the values of A_2 given by the equations in Figure UG-37.1.

All metal in the nozzle wall extending inside the vessel wall A_3 may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening:

(3) metal in attachment welds A_4 and metal added as reinforcement A_5.

(e) With the exception of studding outlet type flanges and the straight hubs of forged nozzle flanges [see UG-44(a)(10)], bolted flange material within the limits of reinforcement shall not be considered to have reinforcing value. With the exception of material within an integral hub, no material in a tubesheet or flat head shall be credited as reinforcement for an opening in an adjacent shell or head.

UG-41 STRENGTH OF REINFORCEMENT

(a) Material used for reinforcement shall have an allowable stress value equal to or greater than that of the material in the vessel wall, except that when such material is not available, lower strength material may be used, provided the area of reinforcement is increased in inverse proportion to the ratio of the allowable stress values of the two materials to compensate for the lower allowable stress value of the reinforcement. No credit may be taken for the additional strength of any reinforcement having a higher allowable stress value than that of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

(b) On each side of the plane defined in UG-40(a), the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the smaller of:

(1) the strength in tension of the cross section of the element or elements of reinforcement being considered (see $W_{1\text{-}1}$, $W_{2\text{-}2}$, and $W_{3\text{-}3}$ of Figure UG-41.1 for examples);

(2) the strength in tension of the area defined in UG-37 less the strength in tension of the reinforcing area that is integral in the vessel wall as permitted by UG-40(d)(1) (see W of Figure UG-41.1 for examples);

(3) for welded attachments, see UW-15 for exemptions to strength calculations.

(c) The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in UG-40. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening that passes through the center of the semicircular end of the opening.

(d) For detailed requirements for welded and brazed reinforcement see the appropriate paragraphs in the Parts devoted to these subjects (see UW-15 and UB-19).

UG-42 REINFORCEMENT OF MULTIPLE OPENINGS

(See UG-39 for multiple openings in flat heads.)

(a) When any two openings are spaced such that their limits of reinforcement overlap [see Figure UG-42, sketch (a)], the two openings shall be reinforced in the plane connecting the centers, in accordance with the rules of UG-37, UG-38, UG-40, and UG-41 with a combined reinforcement that has an area not less than the sum of the areas required for each opening. No portion of the cross section is to be considered as applying to more than one opening, nor to be considered more than once in a combined area.

(1) The available area of the head or shell between openings having an overlap area shall be proportioned between the two openings by the ratio of their diameters.

(2) For cylinders and cones, if the area of reinforcement between the two openings is less than 50% of the total required for the two openings, the supplemental rules of Mandatory Appendix 1, 1-7(a) and 1-7(c) shall be used.

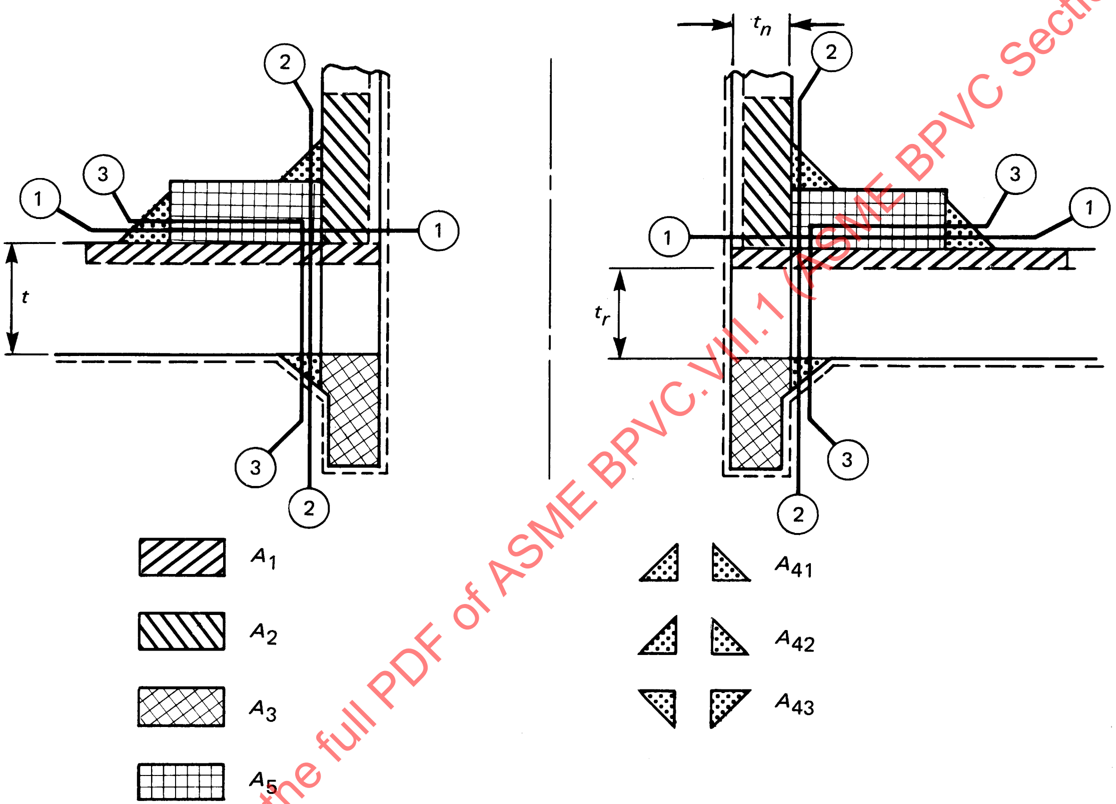
(3) A series of openings all on the same centerline shall be treated as successive pairs of openings.

(b) When more than two openings are spaced as in (a) above [see Figure UG-42, sketch (b)], and are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings shall be $1^1/_3$ times their average diameter, and the area of reinforcement between any two openings shall be at least equal to 50% of the total required for the two openings. If the distance between centers of two such openings is less than $1^1/_3$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings. Such openings must be reinforced as described in (c) below.

(c) Alternatively, any number of adjacent openings, in any arrangement, may be reinforced by using an assumed opening enclosing all such openings. The limits for reinforcement of the assumed opening shall be those given in UG-40(b)(1) and UG-40(c)(1). The nozzle walls of the actual openings shall not be considered to have reinforcing value. For cylinders and cones, when the diameter of the assumed opening exceeds the limits in UG-36(b)(1), the supplemental rules of Mandatory Appendix 1, 1-7(a) and 1-7(c) shall also be used.

(d) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in UW-9(c).

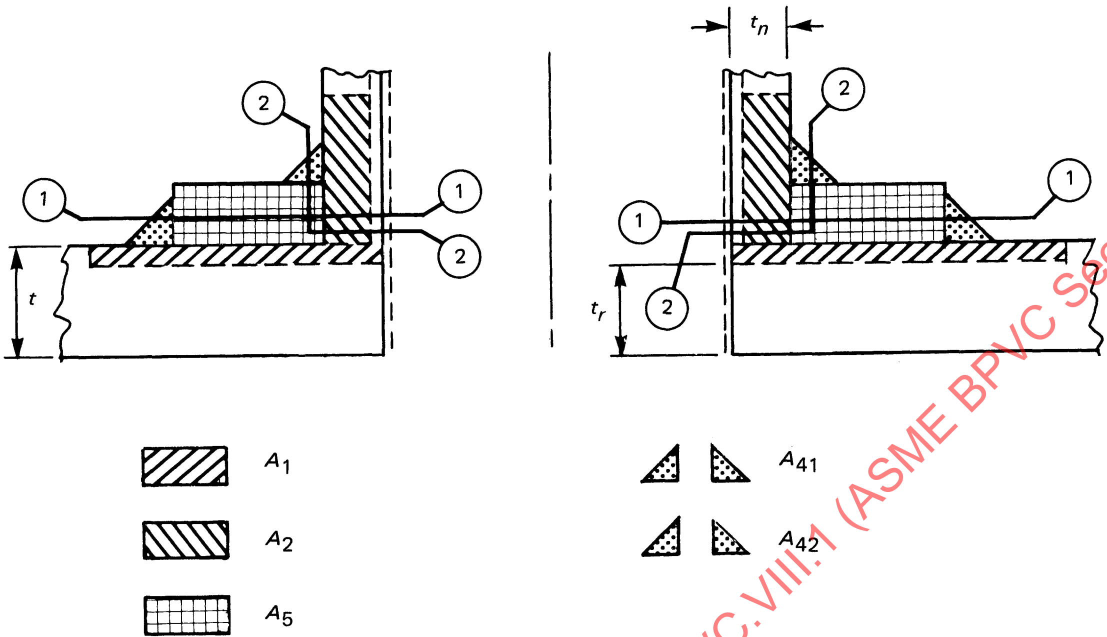
Figure UG-41.1
Nozzle Attachment Weld Loads and Weld Strength Paths to Be Considered



W = total weld load [UG-41(b)(2)]
= $[A - A_1 + 2t_nf_{r1}(E_1t - Ft_r)]S_v$
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
= $(A_2 + A_5 + A_{41} + A_{42})S_v$
$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
= $(A_2 + A_3 + A_{41} + A_{43} + 2t_ntf_{r1})S_v$
$W_{3\text{-}3}$ = weld load for strength path 3-3 [UG-41(b)(1)]
= $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2t_ntf_{r1})S_v$

(a) Depicts Typical Nozzle Detail With Neck Inserted Through the Vessel Wall

Figure UG-41.1
Nozzle Attachment Weld Loads and Weld Strength Paths to Be Considered (Cont'd)



W = total weld load [UG-41(b)(2)]
= $(A - A_1)S_v$
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
= $(A_2 + A_5 + A_{41} + A_{42})S_v$
$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
= $(A_2 + A_{41})S_v$

(b) Depicts Typical Nozzle Detail With Neck Abutting the Vessel Wall

GENERAL NOTES:
(a) Areas A_1, A_2, A_3, A_5, and A_{4i} are modified by f_{rx} factors.
(b) Nomenclature is the same as in UG-37 and Figure UG-37.1.

(e) When a series of two or more openings in a cylindrical or conical shell are arranged in a regular pattern, reinforcement of the openings may be provided per the rules of ligaments in UG-53.

UG-43 METHODS OF ATTACHMENT OF PIPE AND NOZZLE NECKS TO VESSEL WALLS

(a) General. Nozzles may be attached to the shell or head of a vessel by any of the methods of attachment given in this paragraph, except as limited in UG-36.

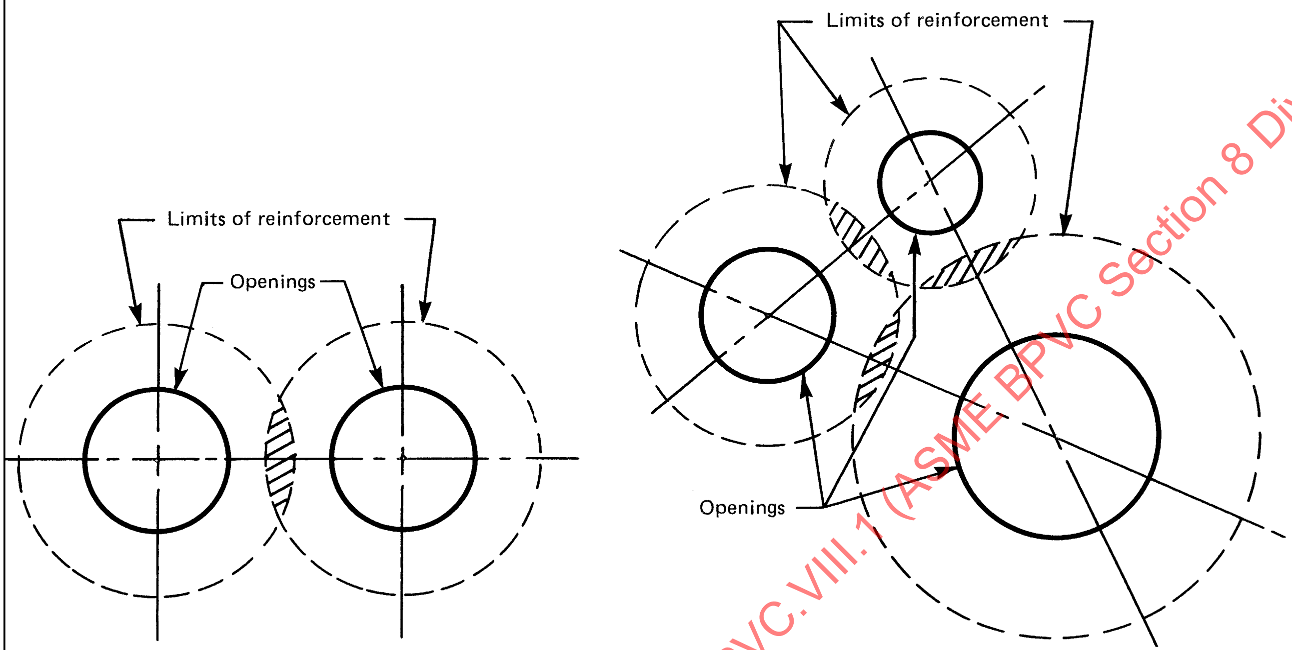
(b) Welded Connections. Attachment by welding shall be in accordance with the requirements of UW-15 and UW-16.

(c) Brazed Connections. Attachment by brazing shall be in accordance with the requirements of UB-17 through UB-19.

(d) Studded Connections. Connections may be made by means of studs. The vessel shall have a flat surface machined on the shell, or on a built-up pad, or on a properly attached plate or fitting. The distance from the inside surface of the vessel to the bottom of a drilled hole to be tapped shall not be less than the corrosion allowance plus one-fourth of the minimum required wall thickness. Weld metal may be added to the inside surface of the vessel to maintain this distance (see UW-42). The tapped holes shall also conform to the requirements of (g) below. Studded connections shall meet the requirements for reinforcement in UG-36 through UG-42.

(e) Threaded Connections. Pipes, tubes, and other threaded connections that conform to the ASME Standard for Pipe Threads, General Purpose, Inch (ASME B1.20.1) may be screwed into a threaded hole in a vessel wall, provided the pipe engages the minimum number of threads specified in Table UG-43 after allowance has been made

Figure UG-42
Examples of Multiple Openings



(a) Two Openings Spaced With Limits of Reinforcement Overlapping

(b) More Than Two Openings Spaced With Limits of Reinforcement Overlapping

for curvature of the vessel wall. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided. A built-up pad or a properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table UG-43, or to furnish reinforcement when required.

Threaded connections larger than 4 in. pipe size (DN 100) shall not be used in vessels that contain liquids having a flash point below 110°F (43°C), or flammable vapors, or flammable liquids at temperatures above that at which they boil under atmospheric pressure.

Threaded connections larger than 3 in. pipe size (DN 80) shall not be used when the maximum allowable working pressure exceeds 125 psi (0.8 MPa), except that this 3 in. pipe size (DN 80) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes, or to integrally forged openings in vessel heads meeting the requirement of UF-43.

(f) Expanded Connections. A pipe, tube, or forging may be attached to the wall of a vessel by inserting through an unreinforced opening and expanding into the shell, provided the diameter is not greater than 2 in. pipe size (DN 50). A pipe, tube, or forging not exceeding 6 in.

Table UG-43
Minimum Number of Pipe Threads for Connections

Size of Pipe Connection, NPS (DN)	Threads Engaged	Min. Plate Thickness Required, in. (mm)
1/2 and 3/4 (DN 15 and 20)	6	0.43 (11.0)
1, 1 1/4, and 1 1/2 (DN 25, 32, and 40)	7	0.61 (15)
2 (DN 50)	8	0.70 (18)
2 1/2 and 3 (DN 65 and 80)	8	1.0 (25)
4–6 (DN 100–150)	10	1.25 (32)
8 (DN 200)	12	1.5 (38)
10 (DN 250)	13	1.62 (41)
12 (DN 300)	14	1.75 (45)

(150 mm) in outside diameter may be attached to the wall of a vessel by inserting through a reinforced opening and expanding into the shell.

Such connections shall be:

(1) firmly rolled in and beaded; or

(2) rolled in, beaded, and seal-welded around the edge of the bead; or

(3) expanded and flared not less than $^1/_8$ in. (3 mm) over the diameter of the hole; or

(4) rolled, flared, and welded; or

(5) rolled and welded without flaring or beading, provided:

(-a) the ends extend at least $^1/_4$ in. (6 mm), but no more than $^3/_8$ in. (10 mm), through the shell;

(-b) the throat of the weld is at least $^3/_{16}$ in. (5 mm), but no more than $^5/_{16}$ in. (8 mm).

When the tube or pipe does not exceed $1^1/_2$ in. (38 mm) in outside diameter, the shell may be chamfered or recessed to a depth at least equal to the thickness of the tube or pipe and the tube or pipe may be rolled into place and welded. In no case shall the end of the tube or pipe extend more than $^3/_8$ in. (10 mm) beyond the shell.

Grooving of shell openings in which tubes and pipe are to be rolled or expanded is permissible.

Expanded connections shall not be used as a method of attachment to vessels used for the processing or storage of flammable and/or noxious gases and liquids unless the connections are seal-welded.

(g) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75 d_s \times \frac{\text{maximum allowable stress value of stud material at design temperature}}{\text{maximum allowable stress value of tapped material at design temperature}}$$

in which d_s is the nominal diameter of the stud, except that the thread engagement need not exceed $1^1/_2 d_s$.

UG-44 FLANGES AND PIPE FITTINGS

(a) The following standards covering flanges and pipe fittings are acceptable for use under this Division in accordance with the requirements of UG-11. Pressure–temperature ratings shall be in accordance with the appropriate standard except that the pressure–temperature ratings for ASME B16.9 and ASME B16.11 fittings shall be calculated as for straight seamless pipe in accordance with the rules of this Division including the maximum allowable stress for the material. The thickness tolerance of the ASME standards shall apply.

(1) ASME B16.1, Gray Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, and 250. Permitted only for pressure vessel parts used on pressure vessels constructed in accordance with Part UCI.

(2) ASME B16.5, Pipe Flanges and Flanged Fittings, NPS $^1/_2$ Through NPS 24 Metric/Inch Standard

(3) ASME B16.9, Factory-Made Wrought Buttwelding Fittings

(4) ASME B16.11, Forged Fittings, Socket-Welding and Threaded

(5) ASME B16.15, Cast Copper Alloy Threaded Fittings, Classes 125 and 250

(6) ASME B16.20, Metallic Gaskets for Pipe Flanges

(7) ASME B16.24, Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves, Classes 150, 300, 600, 900, 1500, and 2500

(8) ASME B16.42, Ductile Iron Pipe Flanges and Flanged Fittings, Classes 150 and 300

(9) ASME B16.47, Large Diameter Steel Flanges, NPS 26 Through NPS 60 Metric/Inch Standard

(10) A forged nozzle flange may use the ASME B16.5/B16.47 pressure–temperature ratings for the flange material being used, provided all of the following are met:

(-a) For ASME B16.5 applications, the forged nozzle flange shall meet all dimensional requirements of a flanged fitting given in ASME B16.5 with the exception of the inside diameter. The inside diameter of the forged nozzle flange shall not exceed the inside diameter of the same size lap joint flange given in ASME B16.5. For ASME B16.47 applications, the inside diameter shall not exceed the weld hub diameter *A* given in the ASME B16.47 tables.

(-b) For ASME B16.5 applications, the outside diameter of the forged nozzle neck shall be at least equal to the hub diameter of the same size and class ASME B16.5 lap joint flange. For ASME B16.47 applications, the outside diameter of the hub shall at least equal the *X* diameter given in the ASME B16.47 tables. Larger hub diameters shall be limited to nut stop diameter dimensions. See Section VIII, Division 2, Figures 4.16.3 and 4.16.4.

(b) External loads (forces and bending moments) may be evaluated for flanged joints with welding neck flanges chosen in accordance with (a)(2), (a)(9), and (a)(10), using the following requirements:

(1) The vessel MAWP (corrected for the static pressure acting on the flange) at the design temperature cannot exceed the pressure–temperature rating of the flange.

(2) The actual assembly bolt load (see Nonmandatory Appendix S) shall comply with ASME PCC-1, Nonmandatory Appendix O.

(3) The bolt material shall have an allowable stress equal to or greater than SA-193 B8 Cl. 2 at the specified bolt size and temperature.

(4) The combination of vessel MAWP (corrected for the static pressure acting on the flange) with external moment and external axial force shall satisfy the following equation (the units of the variables in this equation shall be consistent with the pressure rating):

$$16M_E + 4F_E G \le \pi G^3\left[\left(P_R - P_D\right) + F_M P_R\right]$$

where

F_E = external tensile axial force
F_M = moment factor, in accordance with Table UG-44-1
G = gasket reaction diameter
M_E = external moment
P_D = vessel MAWP (corrected for static pressure acting on the flange) at design temperature
P_R = flange pressure rating at design temperature

UG-45 NOZZLE NECK THICKNESS

The minimum wall thickness of nozzle necks shall be determined as given below.

For access openings and openings used only for inspection:

$$t_{\text{UG-45}} = t_a$$

For other nozzles:

Determine t_b.

$$t_b = \min\left[t_{b3}, \max\left(t_{b1}, t_{b2}\right)\right]$$

$$t_{\text{UG-45}} = \max\left(t_a, t_b\right)$$

where

t_a = minimum neck thickness required for internal and external pressure using UG-27 and UG-28 (plus corrosion and threading allowance), as applicable. The effects of external forces and moments from supplemental loads (see UG-22) shall be considered. Shear stresses caused by UG-22 loadings shall not exceed 70% of the allowable tensile stress for the nozzle material.
t_{b1} = for vessels under internal pressure, the thickness (plus corrosion allowance) required for pressure (assuming E = 1.0) for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16.2 and UG-16.3.
t_{b2} = for vessels under external pressure, the thickness (plus corrosion allowance) obtained by using the external design pressure as an equivalent internal design pressure (assuming E = 1.0) in the formula for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16.2 and UG-16.3.
t_{b3} = the thickness given in Table UG-45 plus the thickness added for corrosion allowance.
$t_{\text{UG-45}}$ = minimum wall thickness of nozzle necks

UG-46 INSPECTION OPENINGS[30]

(a) All pressure vessels for use with compressed air and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (see UG-25),

Table UG-44-1
Moment Factor, F_M (25)

Standard	Size Range	Flange Pressure Rating Class 150	300	600	900	1500	2500
ASME B16.5	≤NPS 12 (≤DN 300)	1.2	0.5	0.5	0.5	0.5	0.5
	>NPS 12 and ≤NPS 24 (>DN 300 and ≤DN 600)	1.2	0.5	0.5	0.3	0.3	...
ASME B16.47							
Series A	All	0.6	0.1	0.1	0.1	...	...
Series B	<NPS 48 (<DN1200)	[Note (1)]	[Note (1)]	0.13	0.13	...	...
	≥NPS 48 (≥DN 1200)	0.1	[Note (2)]	...	...	...	...

GENERAL NOTES:
(a) The combinations of size ranges and flange pressure classes for which this Table gives no moment factor value are outside the scope of this Table.
(b) The designer should consider reducing the moment factor if the loading is primarily sustained in nature and the bolted flange joint operates at a temperature where gasket creep/relaxation will be significant.

NOTES:
(1) F_M = 0.1 + (48 − NPS)/56.
(2) F_M = 0.1, except for NPS 60 (DN 1500), Class 300, in which case F_M = 0.03.

Table UG-45
Nozzle Minimum Thickness Requirements

Nominal Size	Minimum Wall Thickness [See UG-16.4(b)] in.	Minimum Wall Thickness [See UG-16.4(b)] mm
NPS 1/8 (DN 6)	0.060	1.51
NPS 1/4 (DN 8)	0.077	1.96
NPS 3/8 (DN 10)	0.080	2.02
NPS 1/2 (DN 15)	0.095	2.42
NPS 3/4 (DN 20)	0.099	2.51
NPS 1 (DN 25)	0.116	2.96
NPS 1 1/4 (DN 32)	0.123	3.12
NPS 1 1/2 (DN 40)	0.127	3.22
NPS 2 (DN 50)	0.135	3.42
NPS 2 1/2 (DN 65)	0.178	4.52
NPS 3 (DN 80)	0.189	4.80
NPS 3 1/2 (DN 90)	0.198	5.02
NPS 4 (DN 100)	0.207	5.27
NPS 5 (DN 125)	0.226	5.73
NPS 6 (DN 150)	0.245	6.22
NPS 8 (DN 200)	0.282	7.16
NPS 10 (DN 250)	0.319	8.11
≥ NPS 12 (DN 300)	0.328	8.34

GENERAL NOTE: For nozzles having a specified outside diameter not equal to the outside diameter of an equivalent standard NPS (DN) size, the NPS (DN) size chosen from the table shall be one having an equivalent outside diameter larger than the nozzle outside diameter.

except as permitted otherwise in this paragraph, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

Compressed air as used in this paragraph is not intended to include air that has had moisture removed to provide an atmospheric dew point of −50°F (-46°C) or less.

Inspection openings may be omitted in vessels covered in (b), and in heat exchangers where the construction does not permit access to the shell side, such as fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers having shells integral with the tubesheets. When inspection openings are not provided, the Manufacturer's Data Report shall include one of the following notations under "Remarks":

(1) "UG-46(b)" when telltale holes are used in lieu of inspection openings;

(2) "UG-46(a)" when inspection openings are omitted in fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers having shells integral with the tubesheets;

(3) "UG-46(c)", "UG-46(d)", or "UG-46(e)" when provision for inspection is made in accordance with one of these paragraphs;

(4) the statement "for noncorrosive service."

(b) When provided with telltale holes complying with the provisions of UG-25, inspection openings as required in (a) above may be omitted in vessels not over 36 in. (900 mm) I.D. that are subject only to corrosion, provided that the holes are spaced one hole per 10 ft^2 (0.9 m^2) (or fraction thereof) of internal vessel surface area where corrosion is expected with a minimum of four uniformly spaced holes per vessel. This provision does not apply to vessels for compressed air.

(c) Vessels over 12 in. (300 mm) I.D. under air pressure that also contain, as an inherent requirement of their operation, other substances that will prevent corrosion need not have openings for inspection only, provided the vessel contains suitable openings through which inspection can be made conveniently, and provided such openings are equivalent in size and number to the requirements for inspection openings in (f) below.

(d) For vessels 12 in. (300 mm) or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS 3/4 (DN 20).

(e) Vessels less than 16 in. (400 mm) and over 12 in. (300 mm) I.D. shall have at least two handholes or two threaded pipe plug inspection openings of not less than NPS 1 1/2 (DN 40) except as permitted by the following: when vessels less than 16 in. (400 mm) and over 12 in. (300 mm) I.D. are to be installed so that inspection cannot be made without removing the vessel from the assembly, openings for inspection only may be omitted, provided there are at least two removable pipe connections of not less than NPS 1 1/2 (DN 40).

(f) Vessels that require access or inspection openings shall be equipped as follows.[31]

(1) All vessels less than 18 in. (450 mm) and over 12 in. (300 mm) I.D. shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS 1 1/2 (DN 40).

(2) All vessels 18 in. (450 mm) to 36 in. (900 mm), inclusive, I.D. shall have a manhole or at least two handholes or two plugged, threaded inspection openings of not less than NPS 2 (DN 50).

(3) All vessels over 36 in. (900 mm) I.D. shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two openings, each with a minimum area equivalent to a 4 in. × 6 in. (100 mm × 150 mm) handhole.

(4) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(5) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings, provided they are equal at least to the size of the required inspection openings.

(6) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings, provided it is of such size and location as to afford at least an equal view of the interior.

(7) Flanged and/or threaded connections from which piping, instruments, or similar attachments can be removed may be used in place of the required inspection openings, provided that:

(-a) the connections are at least equal to the size of the required openings; and

(-b) the connections are sized and located to afford at least an equal view of the interior as the required inspection openings.

(g) When inspection or access openings are required, they shall comply at least with the following requirements:

(1) An elliptical or obround manhole shall be not less than 12 in. × 16 in. (300 mm × 400 mm). A circular manhole shall be not less than 16 in. (400 mm) I.D.

(2) A handhole opening shall be not less than 2 in. × 3 in. (50 mm × 75 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

(h) All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules of this Division for openings.

(i) When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed in this Division for that material. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided.

(j) Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of $^{11}/_{16}$ in. (17 mm).

BRACED AND STAYED SURFACES

(25) UG-47 BRACED AND STAYED SURFACES

(a) The minimum thickness and maximum allowable working pressure for braced and stayed flat plates and those parts that, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced, shall be calculated by the following equations:

$$t = p\sqrt{\frac{P}{SC}} \quad (1)$$

$$P = \frac{t^2 SC}{p^2} \quad (2)$$

where

C = 2.1 for welded stays or stays screwed through plates not over $^7/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.2 for welded stays or stays screwed through plates over $^7/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.5 for stays screwed through plates and fitted with single nuts outside of plate, or with inside and outside nuts, omitting washers; and for stays screwed into plates as shown in Figure UG-47, sketch (b)
= 2.8 for stays with heads not less than 1.3 times the diameter of the stays screwed through plates or made a taper fit and having the heads formed on the stays before installing them, and not riveted over, said heads being made to have a true bearing on the plate
= 3.2 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than 0.4p and thickness not less than t

P = internal design pressure (see UG-21)

p = maximum pitch. The maximum pitch is the greatest distance between any set of parallel straight lines passing through the centers of staybolts in adjacent rows. Each of the three parallel sets running in the horizontal, the vertical, and the inclined planes shall be considered.

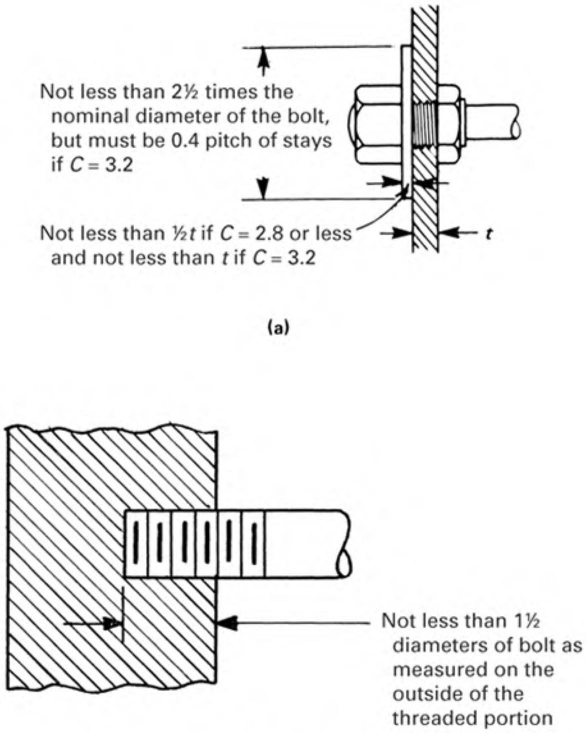
S = maximum allowable stress value in tension (see UG-23)

t = minimum thickness of plate

(b) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be $^5/_{16}$ in. (8 mm) except for welded construction covered by UW-19 or Part UDA.

(c) If a stayed jacket extends completely around a cylindrical or spherical vessel, or completely covers a formed head, it shall meet the requirements given in (a) above, and shall also meet the applicable requirements for shells or heads in UG-27(c) and UG-27(d) and UG-32. In addition, where any nozzle or other opening penetrates the cylindrical or spherical vessel, or completely covered head, and the jacket, the vessel or formed head shall be designed in accordance with UG-37(d)(2).

Figure UG-47
Acceptable Proportions for Ends of Stays



(b) [See Note (1)]

NOTE:
(1) See UG-83.

(d) When two plates are connected by stays and but one of these plates requires staying, the value of C shall be governed by the thickness of the plate requiring staying.

(e) Acceptable proportions for the ends of through stays with washers are indicated in Figure UG-47, sketch (a). See UG-83.

(f) The maximum pitch shall be $8^1/_2$ in. (220 mm), except that for welded-in staybolts the pitch may be greater, provided it does not exceed 15 times the diameter of the staybolt. See UW-19(a) for plate thicknesses greater than $^3/_4$ in. (19 mm).

(g) When the staybolting of shells is unsymmetrical by reason of interference with butt straps or other construction, it is permissible to consider the load carried by each staybolt as the area calculated by taking the distance from the center of the spacing on one side of the bolt to the center of the spacing on the other side.

UG-48 STAYBOLTS

(a) The ends of staybolts or stays screwed through the plate shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the plates, or they shall be fitted with threaded nuts through which the bolt or stay shall extend.

(b) The ends of steel stays upset for threading shall be fully annealed.

(c) Requirements for welded-in staybolts are given in UW-19.

UG-49 LOCATION OF STAYBOLTS

(a) When the edge of a flat stayed plate is flanged, the distance from the center of the outermost stays to the inside of the supporting flange shall not be greater than the pitch of the stays plus the inside radius of the flange.

UG-50 DIMENSIONS OF STAYBOLTS

(a) The required area of a staybolt at its minimum cross section[32] and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt computed in accordance with (b) below by the allowable stress value for the material used, as given in Subsection C, and multiplying the result by 1.10.

(b) Load Carried by Stays. The area supported by a stay shall be computed on the basis of the full pitch dimensions, with a deduction for the area occupied by the stay. The load carried by a stay is the product of the area supported by the stay and the maximum allowable working pressure.

(c) Stays made of parts joined by welding shall be checked for strength using a joint efficiency of 60% for the weld.

LIGAMENTS

UG-53 LIGAMENTS

(a) The symbols used in the equations and charts of this paragraph are defined as follows:

d = diameter of tube holes
n = number of tube holes in length p_1
p = longitudinal pitch of tube holes
p_1 = unit length of ligament
p' = diagonal pitch of tube holes
s = longitudinal dimension of diagonal pitch
= $p' \cos \theta$
θ = angle of diagonal with longitudinal line, deg

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figures UG-53.1 through UG-53.3, the efficiency of the ligaments between the tube holes shall be determined as follows:

(1) When the pitch of the tube holes on every row is equal (see Figure UG-53.1), the formula is

$$\frac{p - d}{p} = \text{efficiency of ligament}$$

(2) When the pitch of tube holes on any one row is unequal (as in Figures UG-53.2 and UG-53.3), the formula is

$$\frac{p_1 - nd}{p_1} = \text{efficiency of ligament}$$

(c) When the adjacent longitudinal rows are drilled as described in (b) above, diagonal and circumferential ligaments shall also be examined. The least equivalent longitudinal efficiency shall be used to determine the minimum required thickness and the maximum allowable working pressure.

(d) When a cylindrical shell is drilled for holes so as to form diagonal ligaments, as shown in Figure UG-53.4, the efficiency of these ligaments shall be determined by Figures UG-53.5 and UG-53.6. Figure UG-53.5 is used to determine the efficiency of longitudinal and diagonal ligaments with limiting boundaries where the condition of equal efficiency of diagonal and longitudinal ligaments form one boundary and the condition of equal efficiency of diagonal and circumferential ligaments form the other boundary. Figure UG-53.6 is used for determining the equivalent longitudinal efficiency of diagonal ligaments. This efficiency is used in the equations for setting the minimum required thickness and the maximum allowable working pressure.

(e) Figure UG-53.5 is used when either or both longitudinal and circumferential ligaments exist with diagonal ligaments. To use Figure UG-53.5, compute the value of p'/p_1 and also the efficiency of the longitudinal ligament. Next find the vertical line in the diagram corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p'/p_1. Then project this point horizontally to the left, and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The minimum shell thickness and the maximum allowable working pressure shall be based on the ligament that has the lower efficiency.

(f) Figure UG-53.6 is used for holes which are not in line, placed longitudinally along a cylindrical shell. The diagram may be used for pairs of holes for all planes between the longitudinal plane and the circumferential plane. To use Figure UG-53.6, determine the angle θ between the longitudinal shell axis and the line between the centers of the openings, θ, and compute the value of p'/d. Find the vertical line in the diagram corresponding to the value of θ and follow this line vertically to the line representing the value of p'/d. Then project this point horizontally to the left, and read the equivalent longitudinal efficiency of the diagonal ligament. This equivalent longitudinal efficiency is used to determine the minimum required thickness and the maximum allowable working pressure.

(g) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable working pressure is based.

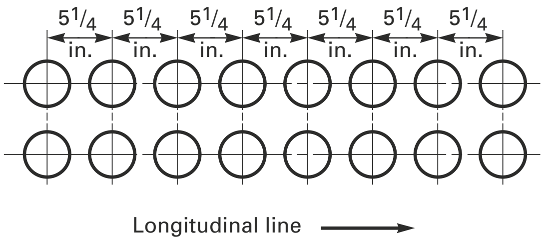
(h) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both:[33]

(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable working pressure is based. When the inside diameter of the shell exceeds 60 in. (1 520 mm), the length shall be taken as 60 in. (1 520 mm) in applying this rule.

(2) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable working pressure is based. When the inside radius of the shell exceeds 30 in. (760 mm), the length shall be taken as 30 in. (760 mm) in applying this rule.

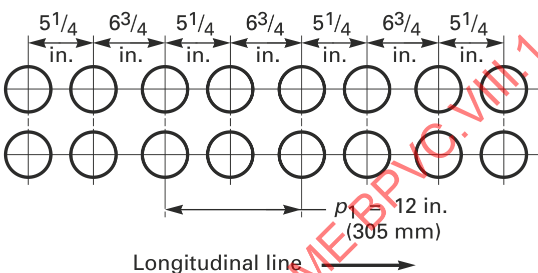
(i) When ligaments occur in cylindrical shells made from welded pipe or tubes, and their calculated efficiency is less than 85% (longitudinal) or 50% (circumferential), the efficiency to be used in the equations of UG-27 is the calculated ligament efficiency. In this case, the appropriate stress value in tension (see UG-23) may be multiplied by the factor 1.18.

Figure UG-53.1
Example of Tube Spacing With Pitch of Holes Equal in Every Row



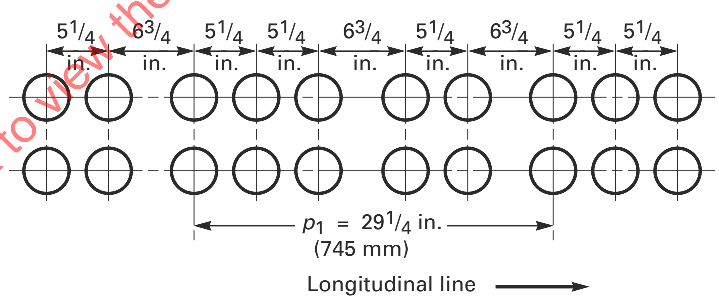
GENERAL NOTE: 5¹⁄₄ in. = 133 mm.

Figure UG-53.2
Example of Tube Spacing With Pitch of Holes Unequal in Every Second Row



GENERAL NOTE: 5¹⁄₄ in. = 135 mm; 6³⁄₄ in. = 170 mm.

Figure UG-53.3
Example of Tube Spacing With Pitch of Holes Varying in Every Second and Third Row



GENERAL NOTE: 5¹⁄₄ in. = 135 mm; 6³⁄₄ in. = 170 mm.

Figure UG-53.4
Example of Tube Spacing With Tube Holes on Diagonal Lines

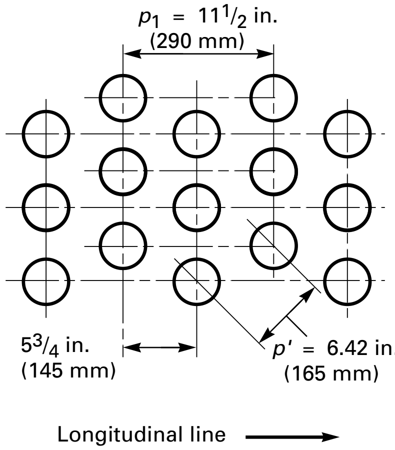
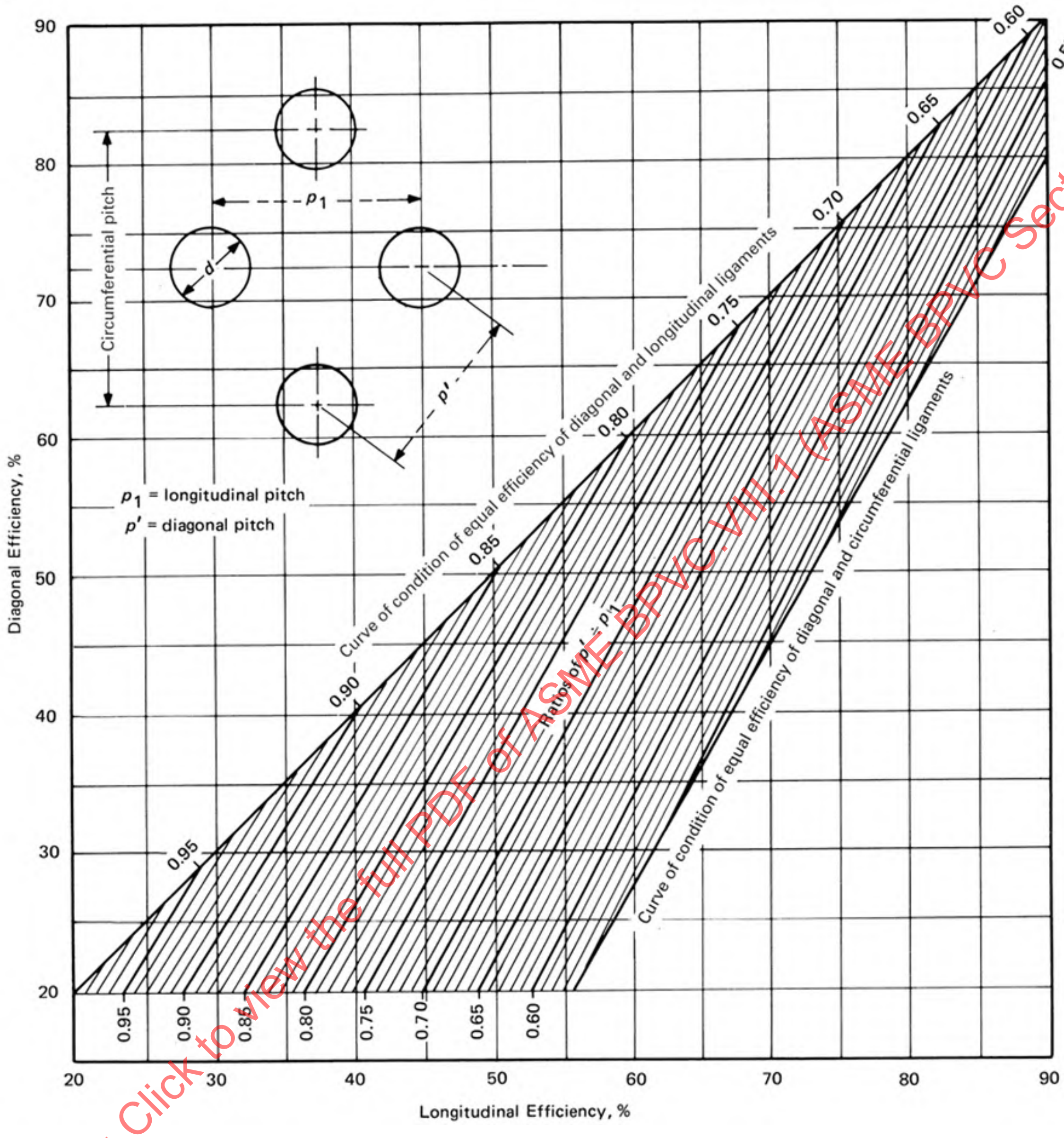


Figure UG-53.5
Diagram for Determining the Efficiency of Longitudinal and Diagonal Ligaments Between Openings in Cylindrical Shells



GENERAL NOTES:

(a) Equations are provided for the user's option in (b), (c), and (d) below. The use of these equations is permitted for values beyond those provided by Figure UG-53.5.

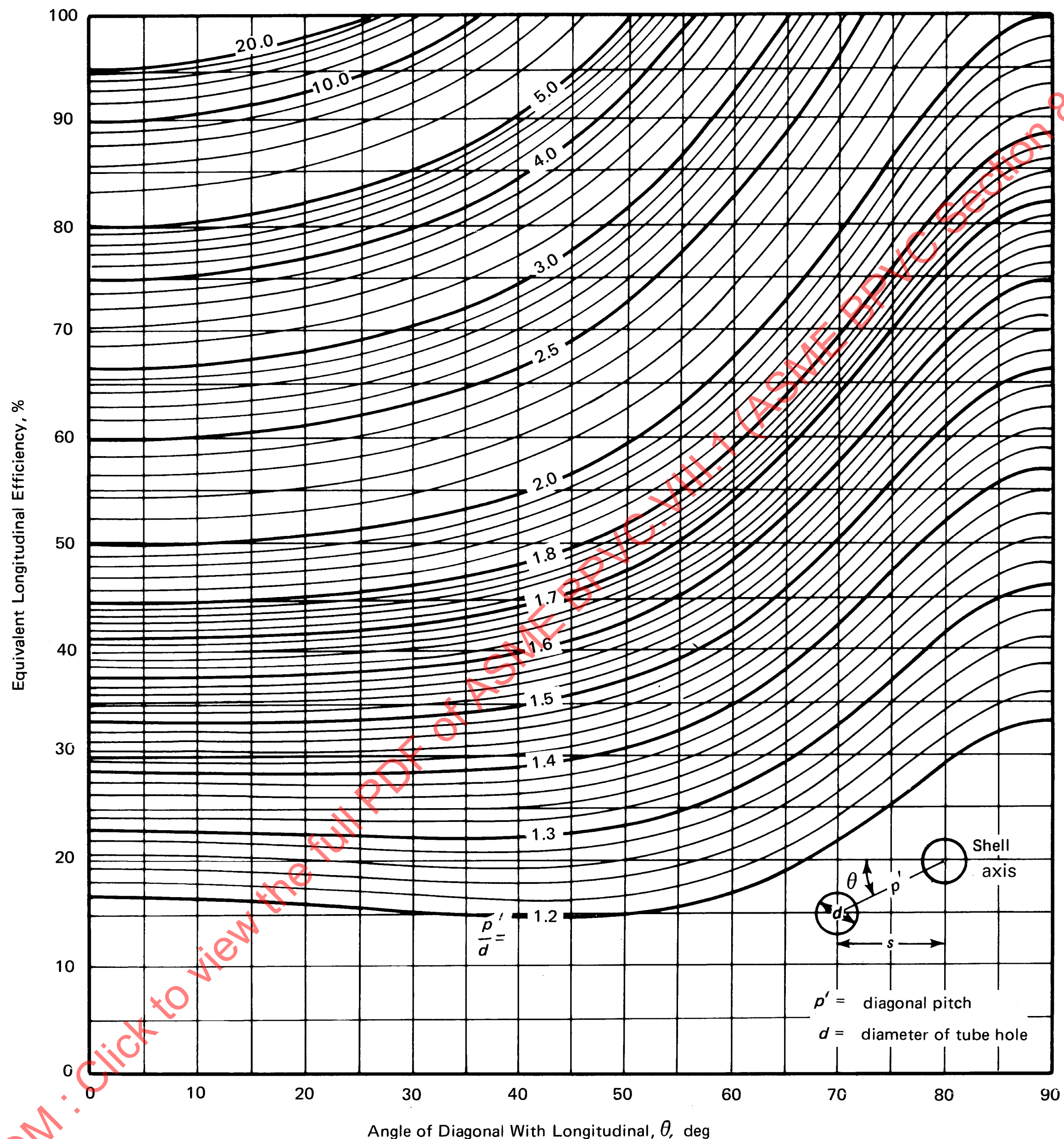
(b) Diagonal efficiency, $\% = \dfrac{J + 0.25 - \left(1 - 0.01E_{\text{long.}}\right)\sqrt{0.75 + J}}{0.00375 + 0.005J}$, where $J = (p'/p_1)^2$

(c) Curve of condition of equal efficiency of diagonal and circumferential ligaments, diagonal efficiency,

$\% = \dfrac{200M + 100 - 2\left(100 - E_{\text{long.}}\right)\sqrt{1 + M}}{\left(1 + M\right)}$, where $M = [(100 - E_{\text{long.}})/(200 - 0.5E_{\text{long.}})]^2$

(d) Longitudinal efficiency, $\% = E_{\text{long.}} = [(p_1 - d)/p_1]\,100$

Figure UG-53.6
Diagram for Determining Equivalent Longitudinal Efficiency of Diagonal Ligaments Between Openings in Cylindrical Shells



GENERAL NOTE: The equation below is provided for the user's option. The use of the equation is prohibited beyond the range of the abscissa and ordinate shown.

$$\text{Equivalent longitudinal efficiency, \%} = \frac{\sec^2\theta + 1 - \left(\dfrac{\sec\theta}{p'/d}\right)\sqrt{3 + \sec^2\theta}}{0.015 + 0.005\sec^2\theta}$$

UG-54 SUPPORTS

(a) All vessels shall be so supported and the supporting members shall be arranged and/or attached to the vessel wall in such a way as to provide for the maximum imposed loadings (see UG-22 and UG-82).

(b) Nonmandatory Appendix G contains suggested rules for the design of supports.

UG-55 LUGS FOR PLATFORMS, LADDERS, AND OTHER ATTACHMENTS TO VESSEL WALLS

(a) Lugs or clips may be welded, brazed, or bolted to the outside or inside of the vessel to support ladders, platforms, piping, motor or machinery mounts, and attachment of insulating jackets (see UG-22). The material of the lugs or clips shall be in accordance with UG-4.

(b) External piping connected to a pressure vessel shall be installed so as not to overstress the vessel wall (see UG-22 and UG-82).

(c) Nonmandatory Appendix G provides guidance on the design of attachments.

FABRICATION

(25) UG-75 GENERAL

Pressure vessels and vessel parts shall be fabricated in accordance with the general requirements in UG-76 through UG-85 and the specific requirements given in the applicable Parts of Subsections B, C, and D.

(25) UG-76 CUTTING MATERIAL

UG-76.1 Plates, edges of heads, and other parts may be cut to shape and size by mechanical or thermal processes. When thermal cutting processes are applied, all slag and detrimental discoloration of previously molten material shall be removed by mechanical processes prior to further fabrication or use.

UG-76.2 Ends of nozzles or access openings that remain unwelded in the completed vessel may be cut by shearing, provided additional material is removed to produce a smooth finish.

UG-76.3 Exposed inside edges shall be chamfered or rounded.

(25) UG-77 MATERIAL IDENTIFICATION (SEE UG-85)

UG-77.1 Marking of Material. Marking of pressure part material shall be performed as specified in (a) through (d).

(a) All materials shall be identified by markings as required within the applicable material specification as specified in UG-93.

(b) Where the service conditions prohibit die stamping for material identification markings, and when so specified by the user, the materials manufacturer shall mark the required data on the material in a manner that will allow positive identification upon delivery. These markings shall be recorded by the vessel Manufacturer so that each piece of material will be positively identified in its position in the completed vessel to the satisfaction of the Inspector.

(c) One complete set of the identification markings required by UG-94 should be plainly visible when the vessel is complete. See UG-77.2.

(d) Transfer of markings shall be done in accordance with UG-77.2 and UG-77.3, as applicable. The Inspector need not witness the transfer of markings but shall verify that it has been properly performed.

UG-77.2 Transfer of Markings by Vessel Manufacturer. Transfer of markings by the vessel Manufacturer shall be performed as specified in (a) through (c).

(a) The pressure vessel Manufacturer shall maintain traceability of the material to the required identification markings by one or more of the following methods:

(1) accurate transfer of the original identification markings to a location where the markings will be visible on the completed vessel

(2) identification by a coded marking traceable to the original identification markings, provided the coded marking system is described in the Manufacturer's written Quality Control System

(3) recording the original identification markings using methods such as material tabulations or as-built sketches that ensure identification of each piece of material during fabrication and subsequent identification in the completed vessel

(b) Transfers of markings shall be made prior to cutting, except that the Manufacturer may transfer markings immediately after cutting provided the control of these transfers is described in the Manufacturer's written Quality Control System (see Mandatory Appendix 10, 10-6).

(c) Except as indicated in UG-77.1(b), material may be marked by any method acceptable to the Inspector.

UG-77.3 Transfer of Markings by Other Than the Vessel Manufacturer. Transfer of markings by other than the vessel Manufacturer shall be performed prior to cutting as specified in (a) through (c).

(a) When material is formed into shapes by anyone other than the Manufacturer of the completed pressure vessel and the original identification marks required by the applicable material specification are unavoidably cut out, or the material is divided into two or more parts, the manufacturer of the shape shall use one of the following methods:

(1) transfer the original identification markings to another location on the shape

(2) provide for identification with a coded marking traceable to the original identification marking using a marking method agreed upon and described in the Quality Control System of the Manufacturer of the completed pressure vessel

(b) Identification in accordance with UG-93, in conjunction with the modified marking requirements in (a), shall be considered sufficient to identify these shapes.

(c) Material identification marking requirements for materials that are wholly formed into shapes that do not include welded joints are found in UG-11(b).

(25) UG-78 REPAIR OF DEFECTS IN MATERIALS

Defects in material may be repaired when the method and extent of repairs are acceptable to the Inspector. Defective material that cannot be satisfactorily repaired shall be rejected

(25) UG-79 FORMING PRESSURE PARTS

UG-79.1 Limits are provided on the cold working of all materials [see UCS-79(d), UNF-79(a), UHA-44(a), and UHT-79(a)]. Forming strains or extreme fiber elongation shall be determined by the equations in Table UG-79-1.

UG-79.2 If the plates are rolled, the adjoining edges of longitudinal joints in cylinders shall be shaped by prerolling or other operations to obtain the proper curvature to avoid flat spots (see UG-80).

UG-79.3 When pressure boundary parts are formed by parties other than the vessel Manufacturer, the required part certification shall indicate whether the part has been hot formed or heat treated after cold forming (see UCS-79, UHA-44, UNF-79, and UHT-79).

UG-79.4 A reduction in weld thickness due to a forming operation is acceptable when all the following conditions are met:

(a) Each weld is verified to comply with UW-35(a) through UW-35(e) by the Manufacturer and the Inspector prior to the forming operation.

(b) The weld thickness after forming shall not be less than the design thickness of the component at any point.

(c) The reduction in thickness shall not exceed the lesser of $^1/_{32}$ in. (0.8 mm) or 10% of the nominal thickness of the adjoining surface.

Table UG-79-1
Equations for Calculating Forming Strains

Type of Part Being Formed	Forming Strain, %
Cylinders formed from plate	$\varepsilon_f = \left(\frac{50t}{R_f}\right)\left(1 - \frac{R_f}{R_o}\right)$
For double curvature (e.g., heads)	$\varepsilon_f = \left(\frac{75t}{R_f}\right)\left(1 - \frac{R_f}{R_o}\right)$
Tube and pipe bends	$\varepsilon_f = \frac{100r}{R}$

Legend:

ε_f = calculated forming strain or extreme fiber elongation
R = nominal bending radius to centerline of pipe or tube
R_f = final mean radius
R_o = original mean radius, equal to infinity for a flat plate
r = nominal outside radius of pipe or tube
t = nominal thickness of the plate, pipe, or tube before forming

UG-80 PERMISSIBLE OUT-OF-ROUNDNESS OF CYLINDRICAL, CONICAL, AND SPHERICAL SHELLS

(a) Internal Pressure. The shell of a completed vessel shall be substantially round and shall meet the following requirements:

(1) The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal diameter at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (see Figure UG-80.2).

(2) When the cross section passes through an opening or within 1 I.D. of the opening measured from the center of the opening, the permissible difference in inside diameters given above may be increased by 2% of the inside diameter of the opening. When the cross section passes through any other location normal to the axis of the vessel, including head-to-shell junctions, the difference in diameters shall not exceed 1%.

For vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

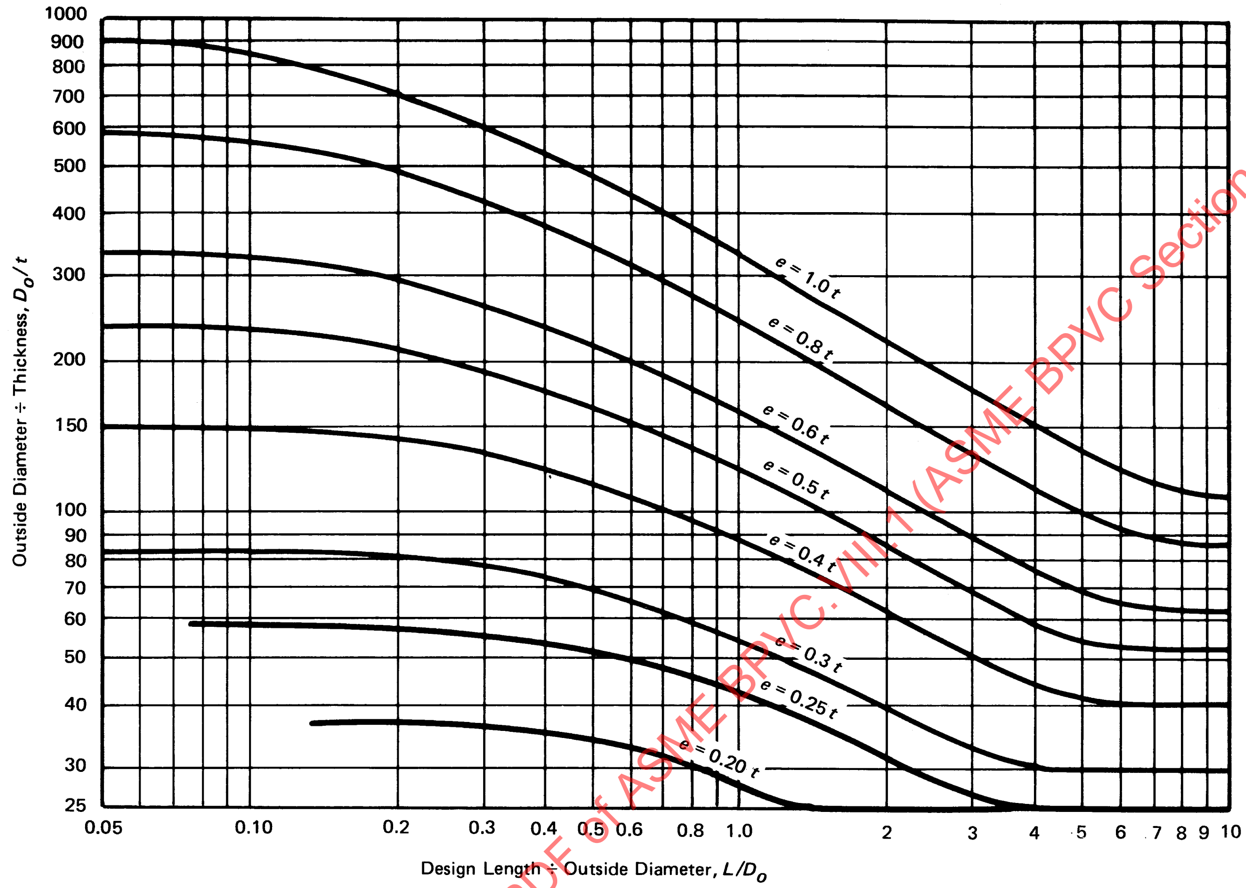
(b) External Pressure. The shell of a completed vessel to operate under external pressure shall meet the following requirements at any cross section:

(1) The out-of-roundness limitations prescribed in (a)(1) and (a)(2) above.

(2) The maximum plus-or-minus deviation from the true circular form, measured radially on the outside or inside of the vessel, shall not exceed the maximum permissible deviation e obtained from Figure UG-80.1. Use e = 1.0t or e = 0.2t, respectively, for points falling above or below these curves. Measurements shall be made from a segmental circular template having the design inside or outside radius (depending upon where the measurements are taken) and a chord length equal to twice the arc length obtained from Figure UG-29.2. The values of L and D_o in Figures UG-29.2 and UG-80.1 shall be determined as follows:

(-a) for cylinders, L and D_o as defined in UG-28(b);

Figure UG-80.1
Maximum Permissible Deviation From a Circular Form *e* for Vessels Under External Pressure



(-b) for cones and conical sections, L and D_o values to be used in the figures are given below in terms of the definitions given in UG-33(b). In all cases below,

$$L_e = 0.5L(1 + D_s/D_L)$$

(-1) at the large diameter end,

$$L = L_e$$

$$D_o = D_L$$

(-2) at the small diameter end,

$$L = L_e(D_L/D_s)$$

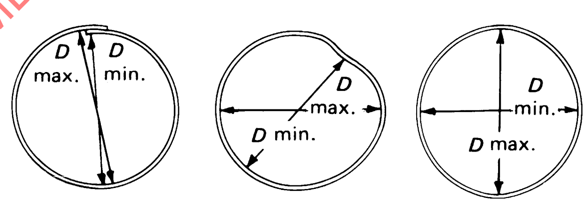
$$D_o = D_s$$

(-3) at the midlength diameter,

$$L = L_e[2D_L/(D_L + D_s)]$$

$$D_o = 0.5\left(D_L + D_s\right)$$

Figure UG-80.2
Example of Differences Between Maximum and Minimum Inside Diameters in Cylindrical, Conical, and Spherical Shells



(-4) at any cross section having an outside diameter of D_x,

$$L = L_e(D_L/D_x)$$

$$D_o = D_x$$

(-c) for spheres, L is one-half of the outside diameter D_o.

(3) For cylinders and spheres, the value of t shall be determined as follows:

(-a) For vessels with butt joints, t is the nominal plate thickness less corrosion allowance.

(-b) For vessels with longitudinal lap joints, t is the nominal plate thickness and the permissible deviation is

$$t + e$$

(-c) Where the shell at any cross section is made of plates having different thicknesses, t is the nominal thickness of the thinnest plate less corrosion allowance.

(4) For cones and conical sections, the value of t shall be determined as in (3) above, except that t in (3)(-a), (3)(-b), and (3)(-c) shall be replaced by t_e as defined in UG-33(b).

(5) The requirements of (2) above shall be met in any plane normal to the axis of revolution for cylinders and cones and in the plane of any great circle for spheres. For cones and conical sections, a check shall be made at locations (2)(-b)(-1), (2)(-b)(-2), and (2)(-b)(-3) above and such other locations as may be necessary to satisfy manufacturers and inspectors that requirements are met.

(6) Measurements shall be taken on the surface of the base metal and not on welds or other raised parts of the material.

(7) The dimensions of a completed vessel may be brought within the requirements of this paragraph by any process which will not impair the strength of the material.

(8) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

(9) If the nominal thickness of plate used for a cylindrical vessel exceeds the minimum thickness required by UG-28 for the external design pressure, and if such excess thickness is not required for corrosion allowance or loadings causing compressive forces, the maximum permissible deviation e determined for the nominal plate thickness used may be increased by the ratio of factor B for the nominal plate thickness used divided by factor B for the minimum required plate thickness; and the chord length for measuring e_{max} shall be determined by D_o/t for the nominal plate thickness used.

(c) Vessels and components fabricated of pipe or tube under internal or external pressure may have permissible variations in diameter (measured outside) in accordance with those permitted under the specification covering its manufacture.

UG-81 TOLERANCE FOR FORMED HEADS

(a) The inner surface of a torispherical, toriconical, hemispherical, or ellipsoidal head shall not deviate outside of the specified shape by more than $1\frac{1}{4}\%$ of D nor inside the specified shape by more than $\frac{5}{8}\%$ of D, where D is the nominal inside diameter of the vessel shell at point of attachment. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than that specified.

(b) Hemispherical heads or any spherical portion of a torispherical or ellipsoidal head designed for external pressure shall, in addition to satisfying (a) above, meet the tolerances specified for spheres in UG-80(b) using a value of 0.5 for L/D_o.

(c) Measurements for determining the deviations specified in (a) above shall be taken from the surface of the base metal and not from welds.

(d) The skirts of heads shall be sufficiently true to round so that the difference between the maximum and minimum inside diameters shall not exceed 1% of the nominal diameter.

(e) When the skirt of any unstayed formed head is machined to make a driving fit into or over a shell, the thickness shall not be reduced to less than 90% of that required for a blank head (see UW-13) or the thickness of the shell at the point of attachment. When so machined, the transition from the machined thickness to the original thickness of the head shall not be abrupt but shall be tapered for a distance of at least three times the difference between the thicknesses.

UG-82 LUGS AND FITTING ATTACHMENTS

All lugs, brackets, saddle type nozzles, manhole frames, reinforcement around openings, and other appurtenances shall be formed and fitted to conform reasonably to the curvature of the shell or surface to which they are attached.

(a) When pressure parts, such as saddle type nozzles, manhole frames, and reinforcement around openings, extend over pressure-retaining welds, such welds shall be ground flush for the portion of the weld to be covered.

(b) When nonpressure parts, such as lugs, brackets, and support legs and saddles, extend over pressure-retaining welds, such welds shall be ground flush as described in (a) above, or such parts shall be notched or coped to clear those welds.

UG-83 HOLES FOR SCREW STAYS

Holes for screw stays shall be drilled full size or punched not to exceed $^1/_4$ in. (6 mm) less than full diameter of the hole for plates over $^5/_{16}$ in. (8 mm) in thickness and $^1/_8$ in. (3 mm) less than the full diameter of the hole for plates not exceeding $^5/_{16}$ in. (8 mm) in thickness, and then drilled or reamed to the full diameter. The holes shall be tapped fair and true with a full thread.

(25) UG-84 CHARPY IMPACT TESTS

UG-84.1 General. Charpy V-notch impact testing of weldments and vessel parts subject to stress due to pressure shall be performed in accordance with the provisions of this paragraph when required by the rules in Subsection C or Subsection D.

UG-84.2 Test Procedures.

(a) Procedures and Apparatus. Impact test procedures and apparatus shall conform to the applicable paragraphs of SA-370 or ISO 148 (Parts 1, 2, and 3).

(b) Product Form Requirements. When impact testing is required and no procedural impact testing requirements are given in the material specification, impact testing of each product form of material shall comply with the requirements of the applicable product form specification listed in Table UG-84.2-1.

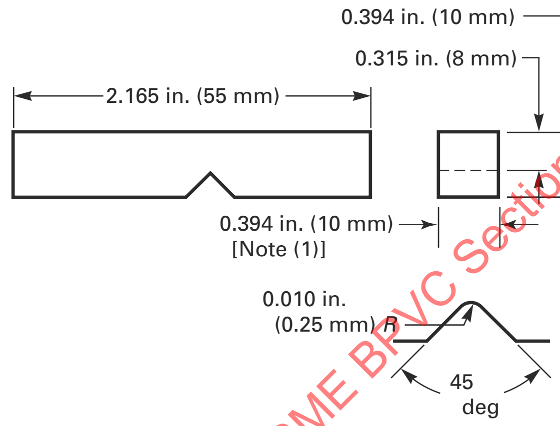
(c) Small Parts. A lot of up to 20 duplicate small cast or forged parts may be certified by testing one set of impact test specimens removed from a single randomly selected part produced of the same specification, heat of material, and heat treatment condition. No impact tests are required when the parts are too small to provide three test specimens meeting the minimum specimen size shown in Figure UG-84.2-1.

(d) Small Vessels. A lot of up to 100 small vessels complying with U-1(j) may be certified by one set of material impact test specimens removed from a single vessel produced of the same heat of material and heat treatment furnace batch.

Table UG-84.2-1
Specifications for Impact Tested Materials in Various Product Forms

Product Form	Spec. No.
Plates	
Parts UCS and UHT	SA-20, S5
Part UHA	SA-480
Pipe	SA-333
Tubes	SA-334
Forgings	SA-350
Castings	SA-352
Bolting materials (and bars)	SA-320
Piping fittings	SA-420

Figure UG-84.2-1
Simple Beam Impact Test Specimens (Charpy Type Test)



NOTE:
(1) See UG-84.3 for thickness of reduced-size specimen.

UG-84.3 Test Specimens.

(a) Each set of impact test specimens shall consist of three test specimens removed from each area required to be tested.

(1) The impact test specimens shall be the Charpy V-notch type and conform in all respects to Figure UG-84.2-1.

(2) Except as permitted in (3) or (c), standard full size 0.394 in. × 0.394 in. (10 mm × 10 mm) test specimens shall be obtained from nominal material thicknesses of $^7/_{16}$ in. (11 mm) or greater.

(3) When full-size specimens cannot be obtained, the test specimens shall be the largest obtainable standard subsize specimens. Alternatively, testing may be performed on specimens using the full nominal material thickness after machining to remove any surface irregularities.

(b) Impact tests are not required when the maximum obtainable test specimen has a width along the notch of less than 0.099 in. (2.5 mm).

(c) For materials demonstrating absorbed energy greater than 180 ft-lb (244 J) when testing full-size test specimens at the specified test temperature, subsize 0.394 in. × 0.262 in. (10 mm × 6.7 mm) test specimens are acceptable in lieu of full-size test specimens [see UG-84.5(g)].

UG-84.4 Test Temperature.

(a) Except when otherwise permitted by Table UG-84.4-1, the impact test temperature shall be no warmer than the minimum design metal temperature (MDMT)[34] [see UG-20(b)] where materials have a nominal thickness

(1) not less than 0.394 in. (10 mm) and the largest obtainable test specimen has a width along the notch of at least 0.315 in. (8 mm)

(2) less than 0.394 in. (10 mm) and the largest obtainable test specimen has a width along the notch of at least 80% of the nominal material thickness

(3) less than 0.394 in. (10 mm) where the largest obtainable test specimen has a width along the notch less than 80% of the nominal material thickness for

(-a) Table UCS-23 material having a minimum tensile strength, S_u, not less than 95,000 psi (655 MPa)

(-b) Table UHT-23 materials, and

(-c) Table UHA-23 materials

(b) Except when applying the alternative rules of UG-84.3(c), the impact test temperature shall be colder than the MDMT by an amount equal to the difference between the temperature reductions shown in Table UG-84.4-2 corresponding to the actual material thickness and the actual test specimen width for Table UCS-23 materials with

(1) a minimum tensile strength, S_u, less than 95,000 psi (655 MPa)

(2) a nominal thickness less than 0.394 in. (10 mm), and

(3) the largest obtainable test specimen has a width along the notch less than 80% of the nominal material thickness

(c) The rules of (a) and (b) above are summarized in Table UG-84.4-3.

(d) The test temperature for welds and heat-affected zones shall not be warmer than the test temperature required for the base materials.

UG-84.5 Acceptance Criteria.

(a) Table UCS-23 materials having a specified minimum tensile strength, S_u, less than 95,000 psi (655 MPa) shall have an impact energy value not less than shown in Figure UG-84.5-1 (Figure UG-84.5-1M) multiplied by the ratio of the actual test specimen width along the notch to the width for a full-size test specimen.

(b) Table UCS-23 materials having a specified minimum tensile strength, S_u, not less than 95,000 psi (655 MPa) shall have a lateral expansion opposite the notch not less than required in UHT-6(a)(3) and UHT-6(a)(4).

Table UG-84.4-1
Impact Test Temperature Differential

Minimum Specified Yield Strength, ksi (MPa)	Temperature Difference, °F (°C) [Note (1)]
≤40 (280)	10 (6)
≤55 (380)	5 (3)
>55 (380)	0 (0)

NOTE:
(1) Impact test temperature may be warmer than the minimum design temperature by the amount shown.

Table UG-84.4-2
Charpy Impact Test Temperature Reduction Below Minimum Design Metal Temperature

Actual Material Thickness [See UG-84.4(a)(2)] or Charpy Impact Specimen Width Along the Notch [Note (1)]	
Thickness, in. (mm)	**Temperature Reduction, °F (°C)**
0.394 (full-size standard bar) (10)	0 (0)
0.354 (9)	0 (0)
0.315 (8.00)	0 (0)
0.295 (3/4 size bar) (7.5)	5 (3)
0.276 (7)	8 (4)
0.262 (2/3 size bar) (6.7)	10 (6)
0.236 (6)	15 (8)
0.197 (1/2 size bar) (5.00)	20 (11)
0.158 (4)	30 (17)
0.131 (1/3 size bar) (3.3)	35 (19)
0.118 (3.00)	40 (22)
0.099 (1/4 size bar) (2.5)	50 (28)

GENERAL NOTE: For Table UCS-23 materials having a specified minimum tensile strength of less than 95,000 psi (655 MPa) when the subsize charpy impact width is less than 80% of the material thickness.

NOTE:
(1) Straight line interpolation for intermediate values is permitted.

(c) Part UHT materials shall meet all requirements of UHT-6(a)(3) and UHT-6(a)(4).

(d) Table UHA-23 materials shall meet all requirements of UHA-51.

(e) Materials produced and impact tested in accordance with the material specification requirements listed in Figure UG-84.5-1 (Figure UG-84.5-1M), General Note (c) shall meet the specified acceptance criteria of the relevant material specification.

(f) Test specimens for welding procedure qualification with impact testing of welds and heat-affected zones and for production impact testing shall achieve impact test values at least as high as those required for the base materials.

(g) For materials tested using subsize specimens as permitted by UG-84.3(c)

(1) the minimum acceptance criteria for each of the subsize test specimens shall be 75 ft-lb (102 J)

(2) the lateral expansion in mils (mm) shall be reported

UG-84.6 Retesting.

(a) If the required impact test acceptance criteria in UG-84.5 are not met, a retest is permitted when one of the following conditions is met for the original test:

(1) The average value is satisfied and only one specimen has a value below two-thirds of the average value required.

Table UG-84.4-3
Impact Test Temperature Criteria

Nominal Material Thickness, t_n	Test Specimen Thickness, t	Specified Material Conditions	Impact Testing Temperature [Note (1)]	Reference Code Paragraph
Any	Any	SMYS < 55 ksi (<380 MPa)	Warmer than MDMT when Table UG-84.4-1 conditions are met	UG-84.4(a)
≥0.394 in. (≥10 mm)	≥0.315 in. (≥8 mm)	All [Note (2)]	Not warmer than MDMT	UG-84.4(a)(1)
<0.394 in. (<10 mm)	≥$0.8t_n$	All [Note (2)]	Not warmer than MDMT	UG-84.4(a)(2)
<0.394 in. (<10 mm)	≥$0.8t_n$	S_u ≥ 95 ksi (≥655 MPa) of Table UCS-23, all Table UHT-23 materials, and all Table UHA-23 materials	Not warmer than MDMT	UG-84.4(a)(3)
<0.394 in. (<10 mm)	<$0.8t_n$	S_u < 95 ksi (<655 MPa) of Table UCS-23 materials [Note (2)]	Colder than MDMT per Table UG-84.4-2	UG-84.4(b)

Legend:

SMYS = specified minimum yield strength
S_u = specified minimum tensile strength

NOTES:
(1) Test temperature may be colder than the minimum specified in the material specification in Section II.
(2) Except for materials addressed in UG-84.3(c).

(2) All three specimens have a value above two-thirds of the average value required for three specimens.

When a retest is permitted, three additional test specimens shall be removed from the same test coupon. The acceptance criteria for each of the retest specimen coupons shall equal or exceed the required average value given in UG-84.5(a).

(b) When an erratic result is caused by a defective specimen or there is uncertainty in test procedure, a retest is permitted.

(c) When the rules of UG-84.3(c) are applied for the initial test and the minimum acceptance value of 75 ft-lb (102 J) is not achieved, retesting using full-size test specimens is permitted.

UG-84.7 Impact Tests of Material.

(a) Reports or certificates of impact testing performed by the material manufacturer demonstrating that the material meets the applicable acceptance criteria of UG-84.5 are acceptable, provided the test specimens comply with the rules of UCS-85, UHT-5, or UHT-81, as applicable.

(b) When impact testing has not been performed by the material manufacturer, the vessel Manufacturer may perform impact tests to prove the suitability of a material.

UG-84.8 Impact Testing of Welds and Heat-Affected Zones.

(a) Welding Procedure Specifications (WPSs) shall be qualified with impact testing when required by UCS-67, UHT-82, or UHA-51. When welding procedure qualification with impact testing is required

(1) the material used for the test coupon shall meet the minimum toughness requirements for thickest base material thickness of the range qualified by the procedure [see Figure UG-84.5-1 (Figure UG-84.5-1M)]

(2) the welding procedures used for fillet welds shall be qualified by groove welded test coupons

(3) the supplementary essential variables in Section IX, QW-250 shall apply

(b) Except for P-No. 1, Group Nos. 1 and 2 materials other than SA-737 and SA-841, the weld test coupon material for vessels constructed of Part UCS materials shall be in the same material heat treatment condition before welding (as rolled, normalized, quenched and tempered, etc.) as the material of construction.

(1) The heat-treatment condition shall be recorded on the procedure qualification record (PQR) and specified on the WPS.

(2) The test coupons shall be subjected to the same postweld heat treatment established by the Manufacturer for production, including the aggregate time at temperature or temperatures.

(3) Heat treatment requirements of UG-85, UCS-85, UHT-81, and UHT-82 shall apply to the test coupons, except the provisions of UCS-85(f) and UCS-85(g) are not applicable.

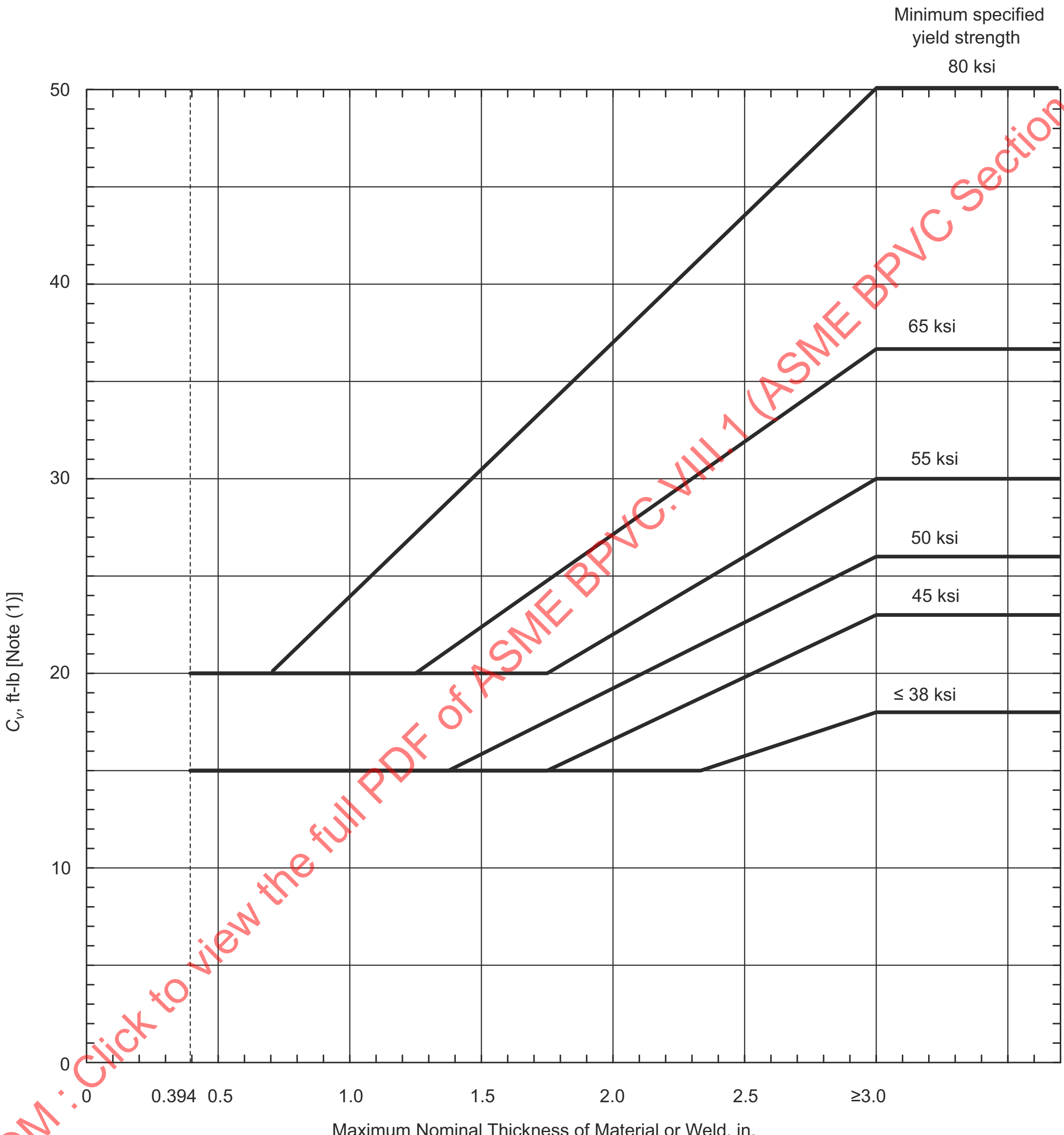
(c) For steel vessels of welded construction, the toughness of welds and heat-affected zones (HAZs) of procedure qualification test coupons and production impact test coupons shall be determined as follows:

(1) Each set of weld metal test specimens shall be taken transverse to the weld axis and prepared with

(-a) the notch located in the weld metal, perpendicular to the surface of the material

(25)

Figure UG-84.5-1
Charpy V-Notch Impact Test Requirements for Full-Size Specimens for Carbon and Low Alloy Steels, Having a Specified Minimum Tensile Strength of Less Than 95 ksi, Listed in Table UCS-23

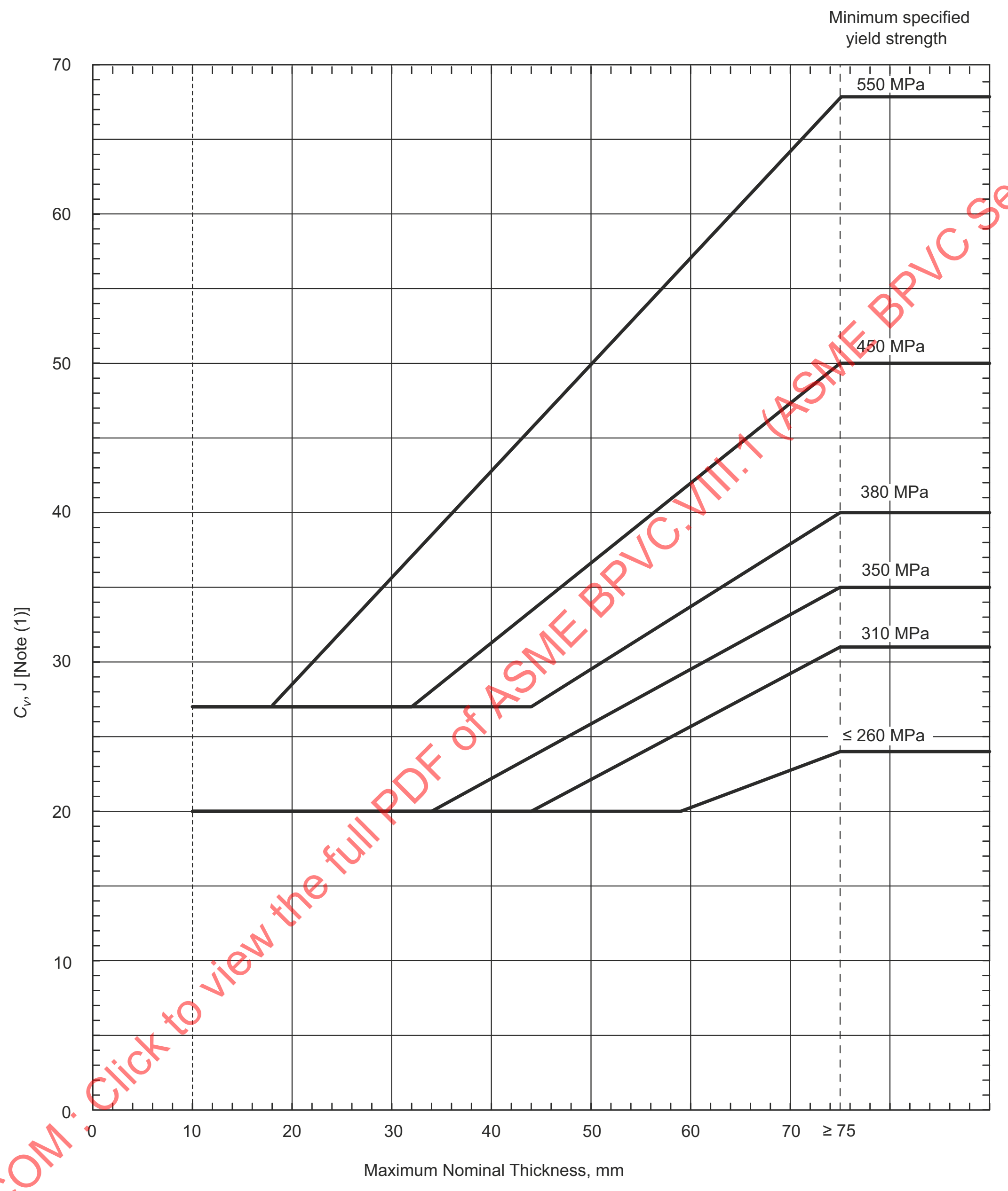


GENERAL NOTES:
(a) Interpolation between yield strengths shown is permitted.
(b) The minimum impact energy for any single specimen shall not be less than $^2/_3$ of the average energy required for three specimens. The average impact energy value of the three specimens may be rounded to the nearest ft-lb.
(c) Material produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, impact tested SA/AS 1548 (*L* impact designations), SA-437, SA-540 (except for materials produced under Table 2, Note 4 in SA-540), and SA-765 do not have to satisfy these energy values. See UCS-66(g).
(d) For materials having a specified minimum tensile strength of 95 ksi or more, see UG-84.5(g).

NOTE:
(1) Average of three specimens.

(25)

Figure UG-84.5-1M
Charpy V-Notch Impact Test Requirements for Full-Size Specimens for Carbon and Low Alloy Steels, Having a Specified Minimum Tensile Strength of Less Than 655 MPa, Listed in Table UCS-23



GENERAL NOTES:
(a) Interpolation between yield strengths shown is permitted.
(b) The minimum impact energy for any single specimen shall not be less than $^2/_3$ of the average energy required for three specimens. The average impact energy value of the three specimens may be rounded to the nearest J.
(c) Material produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, impact tested SA/AS 1548 (*L* impact designations), SA-437, SA-540 (except for materials produced under Table 2, Note 4 in SA-540), and SA-765 do not have to satisfy these energy values. See UCS-66(g).
(d) For materials having a specified minimum tensile strength of 655 MPa or more, see UG-84.5(g).

NOTE:
(1) Average of three specimens.

(-b) one face of the specimen within $^1/_{16}$ in. (1.5 mm) of the surface of the material, except the test specimens may be removed from any depth when the weld has been postweld heat treated

(2) When impact tests are required for the weld metal but the base material is exempt, both the following requirements shall be met:

(-a) The test coupon shall be made from the same P-Number and Group number material as the vessel.

(-b) Impact testing of the weld metal shall be performed, but impact testing of the HAZ is not required.

(3) Each set of HAZ test specimens shall be taken transverse to the axis of the weld and of sufficient length to locate the fusion line after etching.

(-a) Use of a joint design where only one side of the joint is beveled (i.e., a single-bevel or double-bevel groove weld) is recommended to obtain a specimen containing as much of the HAZ as possible. See Figure UG-84.8-1.

(-b) When the material to be tested is less than 1 in. (25 mm) thick, the HAZ test specimens shall be removed from a depth that maximizes the amount of the HAZ at the notch centerline.

(-c) When the material to be tested is 1 in. (25 mm) thick or greater, test specimens prepared shall be removed from coupons prepared as shown in Figure UG-84.8-2 with their centerlines between $^1/_2$ and $^1/_4$ of the material thickness below the surface.

(-d) The notch shall be normal to the material surface.

(-e) When the angle of the HAZ is approximately normal to the material surface, the notch centerline shall be approximately 0.04 in. (1 mm) from the fusion line.

(-f) When the HAZ is at an angle to the material surface, the middle of the notch centerline shall be located approximately 0.08 in. (2 mm) from the fusion line as shown in Figure UG-84.8-1.

(d) Each welding process may be qualified using single-process or multiprocess test coupons.

(1) If more than one set of essential or supplementary essential variables for a process is recorded on a PQR (e.g., different filler metal F-numbers), the requirements for multiprocess testing shall apply for each set of essential or supplementary essential variables as if that set of variables defined a separate welding process.

(2) When more than one welding process is included in a test coupon, the following shall apply:

(-a) The test specimens shall be full-size or the largest obtainable subsize test specimen based on the thickness of the test coupon.

(-b) The weld metal test specimens shall contain as much of the weld metal from each process as practical.

(-c) When the test coupon contains more than two welding processes, additional weld metal impact test specimens shall be removed from the thickness depth where each process is located.

(-d) HAZ test specimens shall be removed from the thickness depth associated with deposited weld metal from each process and may contain HAZ material from more than one welding process.

(-e) When test specimens contain weld metal or HAZs from more than one welding process, the test results shall apply to all the welding processes contained in the specimens.

(-f) Procedure qualifications completed using subsize test specimens tested in accordance with the 2017 Code Edition or later Editions remain acceptable.

(e) When qualifying a WPS for welding base metals having different impact testing requirements and acceptance criteria, the following shall apply:

(1) The weld metal impact test specimens shall meet the acceptance criteria for either base metal.

(2) When HAZ impact tests are required, separate impact test specimens shall be removed from the HAZ of each base metal requiring impact testing, and each set of test specimens shall meet the acceptance criteria for the base metal from which they were removed.

(f) When impact testing of diffusion welded assemblies is required, the diffusion welded assembly test block shall be prepared in accordance with Section IX, QW-185.1.

(1) Two sets of impact test specimens shall be tested with

(-a) one set of specimens removed perpendicular to the interface planes of the test block

(-b) one set of specimens removed parallel to the interface planes of the test block

(2) The impact test temperature and acceptance criteria shall be in accordance with the requirements given in Subsections C and D for the applicable base metal.

UG-84.9 Production Impact Testing.

(a) General. Impact tests of welds and HAZs of production test coupons shall be made in accordance with UG-84.8 for each welding procedure followed on each vessel or group of vessels as defined in (d).

(b) Test Coupon Requirements. The production impact test coupon shall be from one of the heats of steel used for the vessel or group of vessels.

(1) For Category A joints, where practicable, the test coupon shall be welded as an extension to the end of a production joint so that the test coupon weldment will represent the quality and type of welding in the vessel joint.

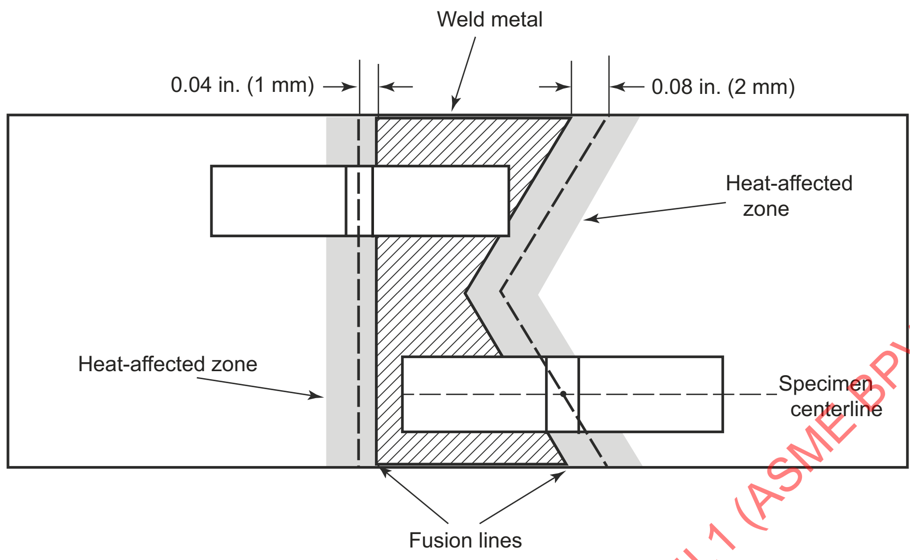
(2) For Category B joints that are welded using a different welding procedure than used on Category A joints, a test coupon shall be welded concurrently with the production welds or as close to the start of production welding as practicable under the same production welding conditions used for the vessel using all the following criteria:

(-a) the same type of equipment

(-b) at the same location

(-c) the same procedure

Figure UG-84.8-1
Location of HAZ Specimen Removal



(c) When Production Impact Test Coupons Are Required

(1) Production impact test coupons shall be made for all joints for which impact tests are required for qualifying the welding procedure by UCS-67, UHT-82, or UHA-51 (except where production impact testing is specifically exempted by these paragraphs).

(2) Tests shall be made of the weld metal and HAZ to the extent required by the procedure qualification test (see UCS-67 and UHA-51).

(d) Number of Vessel Impact Test Coupons Required

(1) For each vessel, one test coupon shall be made for each welding procedure used for Category A and B joints, unless the vessel is one of several as defined in (3) or (4).

(2) For Category A and B joints, the following requirements shall apply:

(-a) If automatic, machine, or semiautomatic welding is performed, a test coupon shall be made in each position employed in the vessel welding.

(-b) If manual welding is employed, a manually welded test coupon shall be made in the flat position.

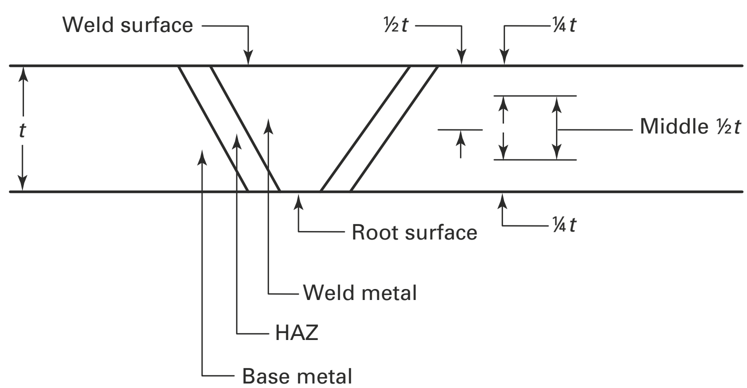
(-c) If welding is to be performed in other positions, a test coupon shall be made in the vertical position.

(-1) The major layers of welds shall be deposited using vertical uphill progression.

(-2) An acceptable test coupon qualifies.

(3) For several vessels or parts of vessels, a minimum of one test coupon shall be made for each welding procedure followed for Category A and B joints, provided the following requirements are met:

Figure UG-84.8-2
HAZ Impact Specimen Removal



(-a) Welding is completed within any 3-month period at one location.

(-b) The cumulative length of all joints represented by a test coupon welded by each welding procedure does not exceed 400 ft (120 m).

(-c) Material is of the same specification and grade.

(-d) The thicknesses of the vessels or parts of vessels do not vary by more than the greater of $^1/_4$ in. (6 mm) or 25%.

(-e) The additional requirements specified in (2) shall be met.

(4) For small vessels complying with U-1(j) made from material requiring impact tests, one welded test joint may represent one lot of the lesser of 100 vessels or one heat treatment furnace batch where the test coupon meets all the following criteria:

(-a) the same heat of material

(-b) the same filler metal

(-c) the same welding procedure

(e) Test Failure. If the production impact test specimen fails to meet the impact testing requirements, the welds represented by the test specimen shall be unacceptable. Reheat treatment and retesting or retesting only are permitted.

(25) UG-85 HEAT TREATMENT

When a required material specification heat treatment is not applied by the material manufacturer, it shall be applied by or under the control of the vessel Manufacturer.

(a) When these heat treatments are completed, the required markings indicating the required specification heat treatments have been performed shall be added to the material identification marking required by the specification.

(b) The Manufacturer shall document completion of the specified heat treatment in accordance with the specification and UG-93.2. See UCS-85, UHT-5(e), and UHT-81 for heat treatment requirements for test specimens.

EXAMINATIONS, INSPECTIONS, AND TESTS

(25) UG-90 GENERAL

UG-90.1 Scope of Applicability. Pressure vessels and vessel parts to be marked with the Certification Mark and the U Designator, vessel parts to be marked with the Certification Mark and the PRT VIII-1 Designator, and miniature pressure vessels [see U-1(j)] to be marked with the Certification Mark and UM Designator shall be fabricated in accordance with all the following:

(a) the applicable general requirements in the following paragraphs

(b) the specific requirements given in the applicable Parts of Subsections B, C, and D

UG-90.2 Manufacturer's Duties and Responsibilities. The Manufacturer is responsible for ensuring that the quality control, detailed examinations, required tests, and all other specifically assigned duties required by this Division are performed. Some of these responsibilities, which are defined in the applicable rules, are summarized as follows:

(a) obtain the Certificate of Authorization from the ASME Accreditation Committee authorizing the Manufacturer to fabricate the type of vessel or vessel part permitted under the scope of authorization [see UG-117(a)]

(b) ensure adequate preparation of drawings and design calculations for the vessel or part [see UG-101; Mandatory Appendix 10, 10-5 and 10-15(d); and Mandatory Appendix 47]

(c) obtain Partial Data Reports when required [see UG-120(c)]

(d) provide access for the Inspector in accordance with UG-92 and Mandatory Appendix 10, 10-15

(e) examine all materials before fabrication to

(1) verify the identification markings on all material used in the fabrication of the vessel or part (see UG-93)

(2) verify that the materials meet the design thickness requirements

(3) detect defects (see UG-93.4)

(4) verify the materials are permitted by this Division (see UG-4)

(5) ensure that traceability (see UG-77) to the material identification and its required documentation has been maintained

(f) document impact tests when required (see UF-5, UCS-66, UHA-51, UHT-6, and ULT-5)

(g) obtain concurrence of the Inspector prior to conducting any base metal repairs (see UG-78 and UF-37)

(h) examine the shell and head sections to confirm they are properly formed to the specified shapes within the permissible tolerances (see UG-79, UG-80, UG-81, UF-27, and UF-29)

(i) qualify the welding or brazing procedures before they are used in fabrication [see UG-84(h), UW-28, and UB-31]

(j) qualify welders, welding operators, brazers, and brazing operators before engaging them in production work (see UW-29, UW-48, UB-32, and UB-43)

(k) examine all parts prior to joining to verify they are properly fitted for welding or brazing, the surfaces to be joined are cleaned, and the alignment tolerances are achieved and maintained (see UW-31, UW-32, UW-33, and UB-17)

(l) examine parts as fabrication progresses for material marking (see UG-94), verify defects are not present (see UG-95), and verify that dimensional geometries are maintained (see UG-96 and UF-30)

(m) provide controls to verify that all required heat treatments are performed and documented (see UW-2; UW-10; UG-85; UF-31; and Mandatory Appendix 10, 10-11)

(n) provide records of nondestructive examinations performed on the vessel or vessel parts, including retention of the reports of nondestructive examination (see UW-51; UW-52; UW-53; Mandatory Appendix 10, 10-13; and Mandatory Appendix 12, 12-4)

(o) conduct the required hydrostatic or pneumatic tests and ensure the required inspections are performed during such tests (see UG-99, UG-100, and UW-50)

(p) apply the required Certification Mark with the applicable designator to the vessel when authorized by the Inspector and verify it is applied to the proper vessel (see UG-116, UG-118, and UG-119)

(q) prepare and certify the required Manufacturer's Data Report and have it certified by the Inspector (see UG-120)

(r) provide for the retention of Manufacturer's Data Reports (see UG-120) and associated records required by this Division (see Mandatory Appendix 10, 10-13)

UG-90.3 Inspector's Duties and Responsibilities. The Inspector shall make all specifically required inspections described below, plus any additional inspections deemed necessary to justify certification and stamping with the Certification Mark with the applicable designator.

(a) Some of the Inspector's required inspections and verifications, which are defined in the applicable rules, are as follows:

(1) verify that the Manufacturer has a valid Certificate of Authorization [see UG-117(a)].

(2) verify that the Manufacturer is working to an accepted Quality Control System [see UG-117(e)] and monitor its implementation (see Mandatory Appendix 10).

(3) verify that the applicable design calculations have been prepared and are available [see U-2(b); U-2(c); and Mandatory Appendix 10, 10-5 and 10-15(d)].

(4) verify that all materials used in the construction of the vessel or vessel parts comply with the requirements of UG-4 through UG-14, including all the following:

(-a) the supporting material documentation accurately represents the material

(-b) the requirements of the material specification have been met (see UG-93)

(-c) the thickness and other dimensions of the materials used in the construction of the vessel or parts comply with the design and requirements of this Division (see UG-80, UG-81, and UG-96)

(-d) the examination and marking requirements have been met for those castings assigned a casting quality factor exceeding 80% (see UG-24)

(5) verify that all welding and brazing procedures have been qualified (see UW-28, UW-47, and UB-42).

(6) verify that all welders, welding operators, brazers, and brazing operators have been qualified (see UW-29, UW-48, and UB-43).

(7) verify that the required heat treatments, including PWHT, have been performed and documented (see UG-85, UW-10, UW-40, UW-49, and UF-52).

(8) verify that any material imperfections repaired by welding are acceptable [see UG-78, UW-52(d)(2)(-c), UF-37, and UF-47(c)].

(9) verify that all weld defects were acceptably repaired [see UW-51(a) and UW-52(c)].

(10) verify that required nondestructive examinations, impact tests, and other tests have been performed and documented and that the results are acceptable (see UG-84, UG-93, UW-50, UW-51, UW-52, and UB-44).

(11) make a visual inspection of the vessel to confirm that the material identification markings have been properly transferred (see UG-77 and UG-94).

(12) make a visual inspection of the vessel to confirm that there are no material or dimensional defects (see UG-95, UG-96, and UG-97).

(13) perform internal and external inspections, witness the hydrostatic or pneumatic tests, and witness any proof tests used to support design (see UG-96, UG-97, UG-99, UG-100, and UG-101).

(14) verify that the required vessel or part markings are applied (see UG-115) and that, if a nameplate (see UG-118) is used, that it is securely attached to the proper vessel or part.

(15) sign the Certificate of Inspection on the Manufacturer's Data Report when, to the best of the Inspector's knowledge and belief, the vessel or part conforms with all the provisions of this Division. When the Inspector indicates acceptance of the vessel or part by signing the Manufacturer's Data Report, this acceptance does not imply any of the responsibilities of the Manufacturer are assumed by the Inspector.

(b) When mass production of pressure vessels makes it impracticable for the Inspector to personally perform all required duties, the Manufacturer, in collaboration with the Inspector, shall

(1) prepare an inspection and quality control procedure setting forth, in complete detail, the method by which the requirements[4] of this Division will be maintained

(2) assure that the quality control procedure is developed, accepted, and implemented in accordance with Mandatory Appendix 35

UG-91 THE INSPECTOR (25)

UG-91.1 Inspectors. All references to "Inspectors" throughout this Division mean the Authorized Inspector as defined herein. All inspections required by this Division shall be performed by an Inspector regularly employed by an ASME accredited Authorized Inspection Agency, as defined in ASME QAI-1.

UG-91.2 Employment Restrictions. The Inspector shall not be employed by the Manufacturer.

UG-91.3 Qualification. All Inspectors shall be qualified in accordance with ASME QAI-1.

(25) UG-92 ACCESS FOR INSPECTOR

UG-92.1 Arrangement for Inspector Access. The Manufacturer of the vessel shall arrange for the Inspector to have free access to all plants or facilities concerned with the supply or manufacture of materials for the vessel, when so requested.

UG-92.2 Free Access for Inspector. The Inspector shall be permitted free access to

(a) the Manufacturer's facility at all times while work on the vessel is being performed

(b) all parts of the Manufacturer's facility that concern the construction of the vessel

(c) the site of field-erected vessels during the period of assembly and testing of the vessel

The Manufacturer shall keep the Inspector informed of the work as it progresses and notify the Inspector reasonably in advance of when vessels or parts will be ready for any required tests or inspections.

(25) UG-93 INSPECTION OF MATERIALS

UG-93.1 Material Acceptance Inspection. Except as otherwise provided in UG-4(b), UG-10, UG-11, or UG-15, the following requirements for accepting materials furnished by the material manufacturer or material supplier to verify complete conformance to a material specification of Section II shall be met:

(a) For plates,[7] the vessel Manufacturer shall ensure all requirements of the material specification and all special requirements of this Division to be fulfilled by the materials manufacturer have been met by obtaining certificates of conformance or Material Test Reports.

(1) These documents shall include results of all required tests and examinations, evidence of conformance to the material specifications, and additional requirements, as applicable.

(-a) When the specification permits certain specific requirements to be completed later, those incomplete items shall be noted on the material documentation.

(-b) When these specific requirements have been completed by someone other than the material manufacturer, this completion shall be documented and attached to the material documentation.

(2) The vessel Manufacturer shall obtain a copy of the test report

(-a) prepared by the material manufacturer, or

(-b) prepared by any subsequent processors responsible for the reported information

(-c) and shall maintain these reports as part of the construction records

(3) If a Material Test Report is supplied by a materials manufacturer, the materials manufacturer may transcribe data produced by other organizations when the material manufacturer accepts responsibility for the accuracy and authenticity of the data.

(b) For all other product forms, the material shall be accepted by the Manufacturer as complying with the material specification when the material specification provides for the marking of each piece with the specification designation, including the grade, type, and class, if applicable, and each piece is so marked.

(c) If the material specification does not provide for the marking of each piece as indicated in (b), the material shall be accepted as complying with the material specification provided the following requirements are met:

(1) Each bundle, lift, or shipping container is marked by the material manufacturer or supplier with the specification designation, including the grade, type, and class, if applicable.

(2) Traceability only to material specification, grade, type, and class, if applicable, is required. Traceability to a specific lot, order, or heat is not required.

(3) The vessel Manufacturer's Quality Control System shall document procedures for the handling, storage, and identification marking of materials.

(d) Pipe or tube material shall be accepted as conforming to the material specification when one of the following conditions is met:

(1) The original markings required by the material specification are present.

(2) A coded marking traceable to the specification designation, including the grade, type, and class, if applicable, is applied to each piece of pipe or tube and both the following conditions are met:

(-a) The marking method has been agreed upon by the material manufacturer or material supplier.

(-b) The marking method has been described in the Quality Control System of the Manufacturer of the completed pressure vessel when one of the following conditions is met:

(-1) The material size is not adequate to display the complete marking in accordance with the material specification.

(-2) The required marking is not provided in accordance with (c).

UG-93.2 Supplementary Certification. Except as otherwise provided in UG-4(b), UG-10, UG-11, or UG-15, when some requirements of a material specification of Section II have been completed by other than the material manufacturer [see UG-84(d) and UG-85], the vessel Manufacturer shall obtain supplementary material test reports or certificates of conformance as described in UG-93.1(a)(2)(-b).

UG-93.3 Supplementary Documentation. When requirements or provisions of this Division applicable to materials exceed or supplement the requirements of the material specification of Section II (see UG-24, UG-84, and UG-85), the vessel Manufacturer shall obtain supplementary material test reports or certificates of conformance as specified in UG-93.1(a)(2)(-a).

UG-93.4 Examination Before Fabrication. All materials to be used in constructing a pressure vessel shall be examined by the Manufacturer before fabrication for imperfections that would affect the safety of the vessel.

(a) Particular attention should be given to cut edges and other parts of rolled plate that may disclose the existence of serious laminations, shearing cracks, and other imperfections.

(b) All materials that require impact testing in accordance with the requirements of UG-84 shall be examined for surface cracks.

(c) When a pressure part is to be welded under the provision of UW-13(e) to form a corner joint with a flat plate thicker than $^1/_2$ in. (13 mm), the examinations specified in (d) shall be applied to

(1) the edge of the flat plate before welding

(2) any remaining exposed edge of the flat plate or surface of the weld joint preparation at the plate edge after welding

(d) The weld joint preparation and the peripheral edges of flat plate forming a corner joint shall be examined by either the magnetic particle or liquid penetrant method as follows:

(1) the weld edge preparation of typical weld joint preparations in the flat plate as shown in Figure UW-13.2, sketches (b), (c), (d), (e-2), (f), and (n)

(2) the outside peripheral edge of the flat plate after welding, as shown in Figure UW-13.2, sketches (a), (b), (c), and (d)

(3) the outside peripheral edge of the flat plate after welding, as shown in Figure UW-13.2, sketches (e-1), (e-2), (f), and (g) if the distance from the edge of the completed weld to the peripheral edge of the flat plate is less than the thickness of the flat plate such as defined in UG-34(b)

(4) the inside peripheral surface of the flat plate after welding, as shown in Figure UW-13.2, sketches (m) and (n)

No examination is required on the flat plate as shown in Figure UW-13.2, sketches (h), (i), (j), (k), and (l). When the plate is nonferromagnetic, only the liquid penetrant method shall be used.

(25) UG-94 MARKING ON MATERIALS

UG-94.1 Material Identification Markings. The Inspector shall inspect materials used in the construction to verify that they bear the identification required by the applicable material specification, except as otherwise provided in UG-4(b), UG-10, UG-11, UG-15, or UG-93.

UG-94.2 Transfer of Identification Markings. Should the material identifying marks be obliterated, or the material be divided into two or more parts, the Inspector shall verify the marks were properly transferred by the Manufacturer as provided in UG-77.2. See UG-85.

UG-95 EXAMINATION OF SURFACES DURING FABRICATION (25)

As fabrication progresses, all materials used in the construction shall be examined for imperfections that have occurred during fabrication to verify the work has been done properly.

UG-96 DIMENSIONAL CHECK OF COMPONENT PARTS (25)

UG-96.1 Shape Conformance. The Manufacturer shall examine the pressure-retaining parts to verify conformance to the prescribed shape and the required design thickness after forming. The Manufacturer of the vessel shall furnish accurately formed templates when required by the Inspector for verification. See UG-80.

UG-96.2 Attachment Conformance. Nozzles, manhole frames, nozzle reinforcements, and other appurtenances to be attached to the inside or outside of the vessel shall be examined to verify proper conformance to the vessel curvature. See UG-82.

UG-96.3 Dimensional Conformance. The Inspector shall verify that the dimensional requirements of UG-96.1 and UG-96.2 have been met by making any dimensional measurement checks that are considered necessary.

UG-97 INSPECTION DURING FABRICATION (25)

UG-97.1 Internal. When conditions permit entry into the vessel, the Inspector shall make an internal examination as complete as possible before final closure.

UG-97.2 External. The Inspector shall make an external inspection of the completed vessel at the time of the final hydrostatic test or pneumatic test.

UG-97.3 Prior to Lead Lining. All welds, including the nozzle welds, of homogeneously lead-lined vessels shall be visually inspected on the inside prior to application of lining. A visual examination of the lining shall be made after completion to ensure that there are no imperfections that might impair the integrity of the lining and subject the vessel to corrosion effects.

UG-98 MAXIMUM ALLOWABLE WORKING PRESSURE

(a) The maximum allowable working pressure for a vessel is the maximum pressure permissible at the top of the vessel in its normal operating position at the designated coincident temperature specified for that pressure. It is the least of the values found for maximum allowable working pressure for any of the essential parts of the

vessel by the principles given in (b) below, and adjusted for any difference in static head that may exist between the part considered and the top of the vessel. (See Mandatory Appendix 3, 3-2.)

(b) The maximum allowable working pressure for a vessel part is the maximum internal or external pressure, including the static head thereon, as determined by the rules and equations in this Division, together with the effect of any combination of loadings listed in UG-22 that is likely to occur, for the designated coincident temperature, excluding any metal thickness specified as corrosion allowance. See UG-25.

(c) Maximum allowable working pressures may be determined for more than one designated coincident temperature, using for each temperature the applicable allowable stress value. See UG-151(e).

(25) UG-99 STANDARD HYDROSTATIC TEST

(a) General. Vessels, including chambers of combination units, designed for internal pressure, except those tested in accordance with UG-100 or UG-101, shall be subjected to a hydrostatic test performed in accordance with this paragraph. Vessels designed for vacuum or partial vacuum only shall be tested in accordance with (f). The pressure test shall be conducted after

(1) all fabrication and assembly have been completed, except for operations that could not be performed prior to the test, such as weld end preparation [see U-1(e)(1)(-a)], and cosmetic grinding on the base material that does not reduce the actual thickness below the design thickness; and

(2) all examinations have been performed, except those required after the test

(b) Minimum Test Pressure. Except as otherwise permitted in (a) and UGL-4, vessels designed for internal pressure shall be subjected to a hydrostatic test pressure that at every point in the vessel is at least equal to 1.3 times the maximum allowable working pressure[35] (MAWP) multiplied by the lowest stress ratio (LSR) for the pressure-boundary materials of which the vessel is constructed. The stress ratio for each pressure-boundary material is the ratio of the stress value S at its test temperature to the stress value S at its design temperature (see UG-21). Bolting shall not be included in the determination of the LSR, except when 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. All loadings that may exist during this test shall be given consideration. The hydrostatic test pressure reading shall be adjusted to account for any static head conditions depending on the difference in elevation between the chamber being tested and the pressure gauge.

(c) Calculated Test Pressure. A hydrostatic test based on a calculated pressure may be used by agreement between the user and the Manufacturer. The hydrostatic test pressure at the top of the vessel shall be the minimum of the test pressures calculated by multiplying the basis for calculated test pressure as defined in Mandatory Appendix 3, 3-2 for each pressure element by 1.3 and reducing this value by the static head of the test fluid on that element. If this pressure is used, the Inspector shall reserve the right to require the Manufacturer or the designer to furnish the calculations used for determining the hydrostatic test pressure for any part of the vessel.

(d) Maximum Test Pressure. The requirements of (b) represent the minimum hydrostatic test pressure required by this Division. The requirements of (c) represent a special test based on calculations. Any intermediate value of pressure may be used. This Division does not specify an upper limit for hydrostatic test pressure. However, if the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined in (c) to the degree that the vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.

(e) Combination Units. Combination units [see UG-19(a) and UG-21] and common elements of chambers that are otherwise exempted per U-1(c)(2)(-f) or U-1(c)(2)(-g) shall be pressure tested in accordance with (1) through (4), as applicable.

(1) Common Elements Subject to Collapse due to External Pressure. During the testing of common elements in accordance with (2) and final assembled combination units in accordance with (3) and (4), common elements subject to collapse (e.g., tubes, inner shell) will be subjected to an external pressure resulting from the pressure test in one of its chambers. The external test pressure acting on a common element shall be limited to 1.3 times its maximum permissible external pressure, calculated at the test temperature using the nominal thickness, including corrosion allowance, and reduced by the static head of the test fluid on the common element. This external test pressure is called the limiting test pressure (LTP). If the LTP is less than the test pressure determined in (b) or (c), as applicable, for the chamber considered, the pressure test on the common element subject to collapse shall be conducted as follows:

(-a) For (2), the test pressure shall not exceed the LTP.

(-b) For (3) and (4), the chambers shall be simultaneously tested such that the test pressure on the common elements does not exceed the LTP while the other elements of the chambers are subjected to the test pressures required by (3) or (4), as applicable.

(-c) The vessel Data Report shall describe the common elements and their LTP. See UG- 120(b).

(2) Common Element Interim Pressure Test. An interim pressure test shall be conducted on completed chambers having visually accessible common elements. The common elements shall be inspected as follows after their fabrication (e.g., tube-to-tubesheet joints, shell long seam in jacketed vessel) and during assembly of the combination unit:

(-a) Welded joints in common elements shall be visually examined and inspected for workmanship.

(-b) The Manufacturer shall conduct an interim hydrostatic test of completed chambers as follows:

(-1) The test pressures shall be in accordance with (3) or (4), as applicable.

(-2) The common elements shall meet the inspection criteria in (h) for combination units.

(-3) The interim pressure test on a chamber of a combination unit may be considered the final pressure test of that chamber provided all the fabrication and assembly, including attachments to the common elements (e.g. welded, bolted) from the adjacent chamber, have been completed prior to the test; otherwise, the interim hydrostatic test shall not be used in lieu of the hydrostatic tests required by (3) or (4) for the assembled combination unit.

(3) Independent Pressure Chambers. Each pressure chamber of a combination unit designed to operate independently shall be hydrostatically tested as a separate vessel, without pressure in the adjacent chamber. If the common elements between chambers are designed for a pressure larger than the MAWP of the chamber being tested, the hydrostatic test shall subject the common elements to a test pressure of at least their design pressure times the LSR as in (b) for the common elements, as well as meet the requirements of (b) or (c) for each independent chamber. The combination unit design and pressure test procedure shall ensure that no chamber elements are overstressed when testing the common elements.

(4) Dependent Pressure Chambers.

(-a) Common elements designed for differential pressure shall be subjected to a hydrostatic test pressure on the higher pressure side. The test pressure shall be at least 1.3 times the maximum differential design pressure times the LSR as in (b) for the common elements.

(-b) Following the test and inspection of the common elements, the adjacent chambers shall be simultaneously tested [see (b) or (c)]. The pressure test procedure shall limit the differential pressure between the chambers to the pressure used when testing the common elements.

(-c) The vessel stamping and the vessel Data Report shall describe the common elements and their limiting differential pressure. See UG-116(j) and UG-120(b).

(f) Vessels Designed for Vacuum or Partial Vacuum Only. Single-wall vessels and individual pressure chambers of combination units designed for vacuum only (MAWP less than or equal to zero) shall be subjected to either

(1) an internal hydrostatic pressure test in accordance with UG-99, or a pneumatic pressure test in accordance with UG-100. The applied test pressure shall be not less than 1.3 times the specified external design pressure; or

(2) a vacuum test conducted at the lowest value of specified absolute internal design pressure. In conjunction with the vacuum test, a leak test shall be performed following a written procedure complying with the applicable technical requirements of Section V, Article 10 for the leak test method and technique specified by the user. Leak testing personnel shall be qualified and certified as required by Section V, Article 1, T-120(e).

(g) Application of Test Pressure.

(1) The test pressure shall not be applied until the vessel and the test fluid are at about the same temperature. See (i).

(2) The pressure shall be gradually increased until the test pressure has been reached.

(3) The test pressure shall be held for a sufficient time to ensure that the pressure is stable and there is no evidence of pressure loss.

(4) If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

(5) Combination Units.

(-a) For combination units having joints that will be visually inaccessible during inspection, the Manufacturer and Inspector shall consider the type(s) of inaccessible joints (e.g., tube-to-tubesheet, flanged, welded) when determining the test pressure holding time.

(-b) The test pressure holding time need not exceed 10 minutes, unless a longer holding time is specified by the user or the user's designated agent.

(-c) Leakage, including that from temporary test closures, shall not be permitted during the test pressure holding time.

(h) Inspection.

(1) Inspection Pressure. Following the application of the hydrostatic test pressure, the pressure shall be reduced to the MAWP and then held for a sufficient time to permit an inspection for leakage in accordance with (2).

(2) Acceptance Criteria.

(-a) Single-Chamber Vessels. A visual inspection for leakage at the inspection pressure shall be made of all joints and connections. Leakage shall not be permitted during inspection, except that leakage from temporary test closures at openings intended for welded connections is allowed provided the inspection pressure is maintained and the leakage does not mask other joints to be inspected.

(-b) Combination Units (Final and Interim Pressure Tests). A visual inspection for leakage at the inspection pressure shall be made of all visually accessible joints and connections. For common elements in combination units that are not visually accessible for inspection, the test may be considered acceptable if there is no loss of pressure and no leakage from temporary test closures during the inspection. The inspection shall also confirm that there is no leakage from visually accessible openings (e.g., nozzles, tubes) in the adjacent chamber.

(-c) Gas Leak Test. The visual inspection required by (-a) or (-b) may be waived, provided all the following requirements are satisfied:

(-1) a suitable gas leak test is applied;

(-2) substitution of the gas leak test is by agreement reached between Manufacturer and Inspector;

(-3) all welded seams that will be hidden by assembly are visually examined and inspected for workmanship prior to assembly;

(-4) the vessel will not contain a "lethal" substance.

(-d) Leaks. If leaks, except as those permitted in (-a), are detected, the following actions shall be taken:

(-1) The vessel shall be depressurized.

(-2) The leaks shall be corrected.

(-3) The vessel shall be retested.

(-e) Permanent Distortion. The Inspector shall reserve the right to reject the vessel if there are any visible signs of permanent distortion.

(3) Depressurization. Upon completion of the inspection, the vessel shall be depressurized gradually to atmosphere before the commencement of any additional work on the vessel.

(i) Minimum Hydrostatic Test Temperature.

(1) Any liquid that is nonhazardous at any temperature may be used for the hydrostatic test if it is below its boiling point. Combustible liquids having a flash point less than 110°F (43°C), such as petroleum distillates, may be used only for near atmospheric temperature tests.

(2) For materials not covered in Part UCS, to minimize the risk of brittle fracture, the coldest metal temperature during the hydrostatic test should be at least 30°F (17°C) warmer than the vessel MDMT and shall never be colder than the vessel MDMT.

(3) For Part UCS materials, to minimize the risk of brittle fracture, the coldest metal temperature during the hydrostatic test should be at least 30°F (17°C) warmer than one of the following, as applicable:

(-a) the MDMT marked on the nameplate when the requirements of UG-20(f) have been met.

(-b) the MDMT marked on the nameplate when the UCS-66(b) or UCS-66(i) coincident ratio has not been applied to calculate the vessel MDMT. The allowable reduction in MDMT permitted by UCS-68.2 may be used when applicable.

(-c) the temperature determined either from Figure UCS-66 (Figure UCS-66M) or from impact testing when the UCS-66(b) or UCS-66(i) coincident ratio has been applied to calculate the vessel MDMT. The allowable reduction in MDMT permitted by UCS-68.2 may be used when applicable.

(4) Further reduction in the coldest metal temperature during the hydrostatic test determined from (3)(-b) or (3)(-c) may be achieved by following the rules in Figure UCS-66.2, with Step 3 modified as shown below.

(-a) Calculate t_r for a pressure equal to the test pressure divided by 1.3 plus pressure due to hydrostatic head, using the allowable stress given in Section II, Part D, Subpart 1 for the material at the pressure test temperature.

(-b) The value of c shall be zero.

(-c) The value of t_n shall be one of the following, as applicable:

(-1) the nominal uncorroded thickness when Part UCL has not been applied

(-2) the nominal thickness of the base material when UCL-23(a) or UCL-23(b) has been applied

(-3) a thickness defined in UCL-23(c) when UCL-23(c) has been applied

(5) The metal temperature during the hydrostatic test need not exceed 120°F (48°C). If the test temperature exceeds 120°F (48°C), inspection of the vessel should be delayed until the temperature is reduced to 120°F (48°C) or less.

CAUTION: A small liquid relief valve set to 1.33 times the test pressure is recommended for the pressure test system, in case a vessel, while under test, is likely to be warmed up materially with personnel absent.

(j) Precautions. Vents shall be provided at all high points of the vessel in the position in which it is to be tested to purge possible air pockets while the vessel is filling.

(k) Test Closures and Equipment.

(1) Temporary Test Closures. The elements used for temporary test closures (e.g., covers, fittings, pipe plugs) and their fasteners (e.g., bolting, welds) shall be sufficient to withstand the test pressure at the test temperature.

(-a) The pressure rating of standard flanges and fittings at the test temperature shall be at least equal to the test pressure divided by 1.3 plus the pressure due to the hydrostatic head of the test fluid.

(-b) For bolted connections, the full complement of bolting shall be used, and the thread engagement shall be in accordance with this Division [see UG-13(a) and UG-43(g)].

(-c) Threaded plugs shall have a thread engagement in accordance with Table UG-43.

(-d) Nonstandard closures shall have supporting calculations that are available to the Inspector.

(-e) Expandable pipe plugs shall be tethered to restrain their movement in the event of slippage or a blowout (e.g., safety gags).

(-f) These elements shall not be used for pressure testing if they show evidence of wear or fatigue that could affect their ability to perform the intended function.

(2) Test Equipment.

(-a) The pressurizing equipment, including test fittings and hoses, shall be rated by the equipment manufacturer to withstand the test pressure to be applied.

(-b) The test equipment shall be periodically checked (e.g., based on usage) and replaced or repaired if it shows evidence of wear or fatigue that could affect its ability to perform the intended function.

(-c) Before applying pressure, the test equipment shall be examined to see that it is tight and that all low-pressure filling lines and other appurtenances that should not be subjected to the test pressure have been disconnected.

(l) Painting and Coating

(1) Unless permitted by the user or the user's designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pressure test. [See UCI-99(b) and UCD-99(b).]

(2) When painting or coating prior to the hydrostatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or the user's designated agent.

(3) Vessels for lethal service [see UW-2(a)]

(-a) shall not be painted or coated either internally or externally prior to the hydrostatic pressure test

(-b) shall not be internally lined by mechanical or welded attachments prior to the hydrostatic pressure test unless the requirements of UCL-51 are followed

(4) The requirements given in (1) and (2) do not apply to glass-lined vessels; see UGL-4.

(m) Flange Assemblies. Custom-designed flange assemblies, including modified standard flange assemblies where additional calculations are required, within the geometric scope of this Division (see Mandatory Appendix 2 and UG-34) shall be tested with gaskets and bolting that meet the following requirements:

(1) be assembled with

(-a) the identical gasket used for operation of the pressure vessel, or

(-b) a gasket with the same outside diameter, inside diameter, thickness, gasket factor (m), and minimum seating stress (y) used in the flange design calculations.

(2) be assembled with bolting having identical allowable stress at room temperature as used in the design calculations.

The user or the user's designated agent may allow either or both requirements to be waived by including such a statement in the General Notes section of Nonmandatory Appendix KK, Form U-DR-1 or Form U-DR-2, or equivalent. The use of test gaskets and bolting with properties differing from those used in the design calculation does not necessarily verify the integrity of flanged joints.

UG-100 PNEUMATIC TEST[36] (SEE UW-50) (25)

(a) General. Subject to the provisions of UG-99(a)(1) and UG-99(a)(2), a pneumatic test prescribed in this paragraph may be used in lieu of the hydrostatic test prescribed in UG-99 for vessels:

(1) that are so designed and/or supported that they cannot safely be filled with water;

(2) not readily dried, that are to be used in services where traces of the testing liquid cannot be tolerated and the parts of which have, where possible, been previously tested by hydrostatic pressure to the pressure required in UG-99.

(b) Test Pressure. Except for enameled vessels, for which the pneumatic test shall be at least equal to, but need not exceed, the MAWP to be marked on the vessel, the pneumatic test pressure at every point in the vessel shall be at least equal to 1.1 times the MAWP multiplied by the lowest stress ratio (LSR) for the pressure-boundary materials of which the vessel is constructed. The stress ratio for each pressure-boundary material is the ratio of the stress value S at its test temperature to the stress value S at its design temperature (see UG-21). Bolting shall not be included in the determination of the LSR, except when 1.1 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. All loadings that may exist during this test shall be given consideration. In no case shall the pneumatic test pressure exceed 1.1 times the basis for the calculated test pressure as defined in Mandatory Appendix 3, 3-2.

(c) Minimum Pneumatic Test Temperature

(1) For materials not covered in Part UCS, to minimize the risk of brittle fracture, the coldest metal temperature during the pneumatic test shall be at least 30°F (17°C) warmer than the vessel MDMT.

(2) For Part UCS materials, to minimize the risk of brittle fracture, the coldest metal temperature during the pneumatic test shall be at least 30°F (17°C) warmer than one of the following, as applicable:

(-a) the MDMT marked on the nameplate when the UCS-66(b) or UCS-66(i) coincident ratio has not been applied to calculate the vessel MDMT. The allowable reduction in MDMT permitted by UCS-68.2 may be used when applicable.

(-b) the temperature determined either from Figure UCS-66 (Figure UCS-66M) or from impact testing when the UCS-66(b) or UCS-66(i) coincident ratio has been applied to calculate the vessel MDMT. The allowable reduction in MDMT permitted by UCS-68.2 may be used when applicable.

(3) Further reduction in the coldest metal temperature during the pneumatic test determined from (2) may be achieved by following the rules in Figure UCS-66.2, with Step 3 modified as shown below.

(-a) Calculate t_r for a pressure equal to the test pressure divided by 1.1, using the allowable stress given in Section II, Part D, Subpart 1 for the material at the pressure test temperature.

(-b) The value of c shall be zero.

(-c) The value of t_n shall be one of the following, as applicable:

(-1) the nominal uncorroded thickness when Part UCL has not been applied

(-2) the nominal thickness of the base material when UCL-23(a) or UCL-23(b) has been applied

(-3) a thickness defined in UCL-23(c) when UCL-23(c) has been applied

(4) The metal temperature during the pneumatic test need not exceed 120°F (48°C). If the test temperature exceeds 120°F (48°C), inspection of the vessel should be delayed until the temperature is reduced to 120°F (48°C) or less.

(d) Combination Units. Combination units [see UG-19(a) and UG-21] and common elements of chambers that are otherwise exempted per U-1(c)(2)(-f) or U-1(c)(2)(-g) shall be pressure tested in accordance with (1) through (4), as applicable.

(1) Common Elements Subject to Collapse due to External Pressure. During the testing of common elements in accordance with (2) and final assembled combination units in accordance with (3) and (4), common elements subject to collapse (e.g., tubes, inner shell) will be subjected to an external pressure resulting from the pressure test in one of its chambers. The external test pressure acting on a common element shall be limited to 1.1 times its maximum permissible external pressure, calculated at the test temperature using the nominal thickness, including corrosion allowance, and reduced by the static head of the test fluid on the common element. This external test pressure is called the Limiting Test Pressure (LTP). If the LTP is less than the test pressure determined in (b) for the chamber considered, the pressure test on the common element subject to collapse shall be conducted as follows:

(-a) For (2), the test pressure shall not exceed the LTP.

(-b) For (3) and (4), the chambers shall be simultaneously tested such that the test pressure on the common elements does not exceed the LTP while the other elements of the chambers are subjected to the test pressures required by (3) or (4), as applicable.

(-c) The vessel Data Report shall describe the common elements and their LTP. See UG-120(b).

(2) Common Element Interim Pressure Test. An interim pressure test shall be conducted on completed chambers having visually accessible common elements. The common elements shall be inspected as follows after their fabrication (e.g., tube-to-tubesheet joints, shell long seam in jacketed vessel) and during assembly of the combination unit.

(-a) Welded joints in common elements shall be visually examined and inspected for workmanship.

(-b) The Manufacturer shall conduct an interim pneumatic test of completed chambers as follows:

(-1) The test pressures shall be in accordance with (3) or (4), as applicable.

(-2) The common elements shall meet the inspection criteria in (f) for combination units.

(-3) The interim pressure test on a chamber of a combination unit may be considered the final pressure test of that chamber provided all the fabrication and assembly, including attachments to the common elements (e.g., welded, bolted) from the adjacent chamber, have been completed prior to the test; otherwise, the interim pneumatic test shall not be used in lieu of the pneumatic tests required by (3) or (4) for the assembled combination unit.

(3) Independent Pressure Chambers. Each pressure chamber of a combination unit designed to operate independently shall be pneumatically tested as a separate vessel without pressure in the adjacent chamber. If the common elements between chambers are designed for a pressure larger than the MAWP of the chamber being tested, the pneumatic test shall subject the common elements to a test pressure of at least their design pressure times the LSR as in (b) for the common elements, as well as meet the requirements of (b) for each independent chamber. The combination unit design and pressure test procedure shall ensure that no chamber elements are overstressed when testing the common elements.

(4) Dependent Pressure Chambers.

(-a) Common elements designed for differential pressure shall be subjected to a pneumatic test pressure on the higher pressure side. The test pressure shall be at least 1.1 times the maximum differential design pressure times the LSR as in (b) for the common elements.

(-b) Following the test and inspection of the common elements, the adjacent chambers shall be simultaneously tested [see (b)]. The pressure test procedure shall limit the differential pressure between the chambers to the pressure used when testing the common elements.

(-c) The vessel stamping and the vessel Data Report shall describe the common elements and their limiting differential pressure. See UG-116(j) and UG-120(b).

(e) Application of Test Pressure.

(1) The test pressure shall not be applied until the vessel and the test fluid are at about the same temperature. See (c).

(2) The pressure shall be gradually increased until one-half of the test pressure is reached, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the test pressure has been reached.

(3) The test pressure shall be held for a sufficient time to ensure that the pressure is stable and there is no evidence of pressure loss.

(4) If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

(5) Combination Units.

(-a) For combination units having joints that will be visually inaccessible during inspection, the Manufacturer and Inspector shall consider the type(s) of inaccessible joints (e.g., tube-to-tubesheet, flanged, welded) when determining the test pressure holding time.

(-b) The test pressure holding time need not exceed 10 minutes, unless a longer holding time is specified by the user or the user's designated agent.

(-c) Leakage, including that from temporary test closures, shall not be permitted during the test pressure holding time.

(f) Inspection.

(1) Inspection Pressure. Following the application of the pneumatic test pressure, the pressure shall be reduced to the MAWP, and then held for a sufficient time to permit an inspection for leakage in accordance with (2).

(2) Acceptance Criteria.

(-a) Single-Chamber Vessels. A visual inspection for leakage at the inspection pressure shall be made of all joints and connections and of all regions of high stress, such as knuckles of formed heads, cone-to-cylinder junctions, regions around openings, and thickness transitions. Leakage shall not be permitted during inspection, except that leakage from temporary test closures at openings intended for welded connections is allowed provided the inspection pressure is maintained and the leakage does not mask other joints to be inspected.

(-b) Combination Units (Final and Interim Pressure Tests). A visual inspection for leakage at the inspection pressure shall be made of all visually accessible joints and connections and of all regions of high stress, such as knuckles of formed heads, cone-to-cylinder junctions, regions around openings, and thickness transitions. For common elements in combination units that are not visually accessible for inspection, the test may be considered acceptable if there is no loss of pressure and no leakage from temporary test closures during the inspection. The inspection shall also confirm that there is no leakage from visually accessible openings (e.g., nozzles, tubes) in the adjacent chamber.

(-c) Gas Leak Test. The visual inspection required by (-a) or (-b) may be waived, provided all of the following requirements are satisfied:

(-1) a suitable gas leak test is applied;

(-2) substitution of the gas leak test is by agreement reached between Manufacturer and Inspector;

(-3) all welded seams that will be hidden by assembly are visually examined and inspected for workmanship prior to assembly;

(-4) the vessel will not contain a "lethal" substance.

(-d) Leaks. If leaks, except as those permitted in (-a), are detected, the following actions shall be taken:

(-1) The vessel shall be depressurized.

(-2) The leaks shall be corrected.

(-3) The vessel shall be retested.

(-e) Permanent Distortion. The Inspector shall reserve the right to reject the vessel if there are any visible signs of permanent distortion.

(3) Depressurization. Upon completion of the inspection, the vessel shall be depressurized gradually to atmosphere before the commencement of any additional work on the vessel.

(g) Precautions. Air or gas is hazardous when used as a testing medium. It is therefore recommended that the vessel be tested in such a manner as to ensure personnel safety from a release of the total internal energy of the vessel. See also ASME PCC-2, Article 501, Mandatory Appendices 501-II and 501-III.

(h) Test Closures and Equipment.

(1) Temporary Test Closures. The elements used for temporary test closures (e.g., covers, fittings, pipe plugs) and their fasteners (e.g., bolting, welds) shall be sufficient to withstand the test pressure at the test temperature.

(-a) The pressure rating of standard flanges and fittings at the test temperature shall be at least equal to the test pressure divided by 1.1.

(-b) For bolted connections, the full complement of bolting shall be used, and the thread engagement shall be in accordance with this Division [see UG-13(a) and UG-43(g)].

(-c) Threaded plugs shall have a thread engagement in accordance with Table UG-43.

(-d) Nonstandard closures shall have supporting calculations that are available to the Inspector.

(-e) Expandable pipe plugs shall be tethered to restrain their movement in the event of slippage or a blowout (e.g., safety gags).

(-f) These elements shall not be used for pressure testing if they show evidence of wear or fatigue that could affect their ability to perform the intended function.

(2) Test Equipment.

(-a) The pressurizing equipment, including test fittings and hoses, shall be rated by the equipment manufacturer to withstand the test pressure to be applied.

(-b) The test equipment shall be periodically checked (e.g., based on usage) and replaced or repaired if it shows evidence of wear or fatigue that could affect its ability to perform the intended function.

(-c) Before applying pressure, the test equipment shall be examined to see that it is tight and that all low-pressure filling lines and other appurtenances that should not be subjected to the test pressure have been disconnected.

(i) Painting and Coating

(1) Unless permitted by the user or the user's designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pneumatic pressure test.

(2) When painting or coating prior to the pneumatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or the user's designated agent.

(3) Vessels for lethal service [see UW-2(a)]

(-a) shall not be painted or coated either internally or externally prior to the pneumatic pressure test

(-b) shall not be internally lined by mechanical or welded attachments prior to the pneumatic pressure test unless the requirements of UCL-51 are followed

(j) Flange Assemblies. Custom-designed flange assemblies, including modified standard flange assemblies where additional calculations are required, within the geometric scope of this Division (see Mandatory Appendix 2 and UG-34) shall be tested with gaskets and bolting that meet the following requirements:

(1) be assembled with

(-a) the identical gasket used for operation of the pressure vessel, or

(-b) a gasket with the same outside diameter, inside diameter, thickness, gasket factor (m), and minimum seating stress (y) used in the flange design calculations

(2) be assembled with bolting having identical allowable stress at room temperature as used in the design calculations

The user or the user's designated agent may allow either or both requirements to be waived by including such a statement in the General Notes section of Nonmandatory Appendix KK, Form U-DR-1 or Form U-DR-2, or equivalent. The use of test gaskets and bolting with properties differing from those used in the design calculation does not necessarily verify the integrity of flanged joints.

(25) UG-101 PROOF TESTS TO ESTABLISH MAXIMUM ALLOWABLE WORKING PRESSURE

(a) General

(1) The maximum allowable working pressure for vessels or vessel parts for which the strength cannot be computed with a satisfactory assurance of accuracy (see U-2) shall be established in accordance with the requirements of this paragraph, using one of the test procedures applicable to the type of loading and to the material used in construction. Production vessels or vessel parts that utilize the results of a proof test shall comply with all applicable construction rules of the current edition and applicable addenda of this Division.

(-a) Consideration of the use of proof-tested construction specifications based on past editions of this Division and documented in the original Proof Test Report requires that the Manufacturer determine whether or not there have been subsequent revisions to this Division that apply and must be evaluated. This evaluation may void the Division acceptability of establishing the vessel MAWP by proof testing (e.g., UCS-66, Part UHX, Part UNC, etc.). However, if applicable revisions are found, and it is judged that a new proof test is not required, the Manufacturer, using Duplicate and Similar Parts rules in (d) as guidelines, shall prepare a Supplement to the original Proof Test Report documenting any changes to the construction requirements and to the Manufacturer's Data Report. The following should be noted:

(-1) The production vessel material need not be identical with that used for the original proof tested vessel, but material equivalence must be confirmed and documented.

(-2) The MDMT established by current Division rules may be different from that originally assigned but must be suitable for the nameplate MDMT marking coincident with the established MAWP.

(-3) The Supplement to the original Proof Test Report shall be made available to the Inspector prior to the start of construction.

(2) Provision is made in these rules for two types of tests to determine the internal maximum allowable working pressure:

(-a) tests based on yielding of the part to be tested. These tests are limited to materials with a ratio of minimum specified yield to minimum specified ultimate strength of 0.625 or less.

(-b) tests based on bursting of the part.

(3) Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in (m) below.

(4) The Code recognizes that Manufacturers may maintain control of proof test reports under different ownerships than existed during the original application of the proof test. When a Manufacturer is acquired by a new owner(s), the proof test reports may be used by the new owner(s) without retesting, provided all of the following are met:

(-a) the new owner(s) takes responsibility for the proof tests;

(-b) the Proof Test Reports reflect the name of the new owner(s);

(-c) the Proof Test Reports indicate the actual test was performed by the former Manufacturer;

(-d) the Proof Test Report(s) is acceptable to the Inspector of the new owner(s) as indicated by the Inspector's signature on the Manufacturer's report of the test.

(5) Manufacturers owned by the same entity may share proof testing report(s) when the following conditions are met:

(-a) Each Manufacturer maintain a Quality Control System (see Mandatory Appendix 10) that describes the effective operational control and authority for technical

implementation of shared Manufacturer's proof testing reports, fabrication drawings, and procedures for assembly of the vessel, when necessary.

(-b) Fabrication drawings and welding, brazing and bolting procedures used by each Manufacturer are identical to those used to produce the proof testing report(s) within the requirements stated in UG-101.

(-c) Each Manufacturer takes full responsibility for each shared proof testing report and documents this, indicating the specific proof test performed by the original qualifying Manufacturer and the location where the proof test was performed.

(-d) Each Manufacturer submits the shared proof test report(s) to the Inspector for acceptance.

(-e) Welding and brazing procedures qualified to Section IX may be qualified at each Manufacturer's location but shall be identical, with respect to variables used, to the procedures used to weld or braze the proof-tested object for a shared proof testing report.

(-f) When the original qualifying Manufacturer no longer holds a valid ASME U Certificate of Authorization or has a name change, the previously accepted shared Manufacturer's proof testing report(s) remain valid.

(b) The tests in these paragraphs may be used only for the purpose of establishing the maximum allowable working pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Division. The maximum allowable working pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

Tests to establish the maximum allowable working pressure of vessels, or vessel parts, shall be witnessed by and be acceptable to the Inspector, as indicated by the Inspector's signature on the Manufacturer's Proof Test Report. The report shall include sufficient detail to describe the test, the instrumentation and the methods of calibration used, and the results obtained. The report shall be made available to the Inspector for each application [see U-2(b) and UG-90.2(b)].

(c) The vessel or vessel part for which the maximum allowable working pressure is to be established shall not previously have been subjected to a pressure greater than 1.3 times the desired or anticipated maximum allowable working pressure, adjusted for operating temperature as provided in (k) below.

(d) Duplicate and Similar Parts. When the maximum allowable working pressure of a vessel or vessel part has been established by a proof test, duplicate parts, or geometrically similar parts, that meet all of the requirements in (1) or (2) below, need not be proof tested but shall be given a hydrostatic pressure test in accordance with UG-99, or a pneumatic pressure test in accordance with UG-100, except as otherwise provided in UCI-101, and UCD-101.

(1) Duplicate Parts. All of the following requirements shall be met in order to qualify a part as a duplicate of the part that had been proof tested:

(-a) same basic design configuration and type of construction;

(-b) the material of the duplicate part is either:

(-1) the same material specifications:

(+a) alloy;

(+b) grade, class;

(+c) type, form;

(+d) heat treatment; or

(-2) the same or closely similar material when only the material specification, the alloy, grade, or form is different, provided the material meets the following additional requirements:

(+a) has allowable stress in tension equal to or greater than the material used in the proof tested part at the test temperature [see (k) below];

(+b) has the same P-Number (Section IX);

(+c) for carbon or low alloy steels (see Part UCS), has the same or tougher material grouping in UCS-66, Figure UCS-66 (Figure UCS-66M), and Notes;

(-c) the nominal dimensions, diameter, or width and height, of the duplicate parts shall be the same, and the corresponding nominal thicknesses shall be the same as those used in the proof test. The length shall not be longer than that proof tested.

(-d) heat treatment shall be the same as performed on the original part that was tested;

(-e) the MAWP shall be calculated according to (e) below;

(-f) when there are permissible deviations from the original part that was proof tested, a supplement to the original Proof Test Report shall be prepared that states and evaluates each deviation.

(2) Geometrically Similar Parts. The maximum allowable working pressure for geometrically similar parts may be established by a series of proof tests that uniformly cover the complete range of sizes, pressure, or other variables by interpolation from smooth curves plotted from the results of the tests.

(-a) Sufficient tests shall be performed to provide at least five data points that are at increments that are within 20% to 30% of the range covered.

(-b) The curves shall be based on the lower bound of the test data.

(-c) Extrapolation is not permitted.

(e) Proof test methods (l), (m), (n), and (o) below establish a pressure at which the test is terminated. The results of the test are recorded in a Proof Test Report according to (b).

(1) The MAWP for the first duplicate part, as defined in (d), to be put into service, shall be calculated according to the equations given in the proof test method applied.

The requirements for NDE are given in UG-24 and UW-12. Other requirements are based on thickness or material. These apply to parts which are to be put into service. It is not necessary to examine the part actually tested.

(2) For subsequent duplicate parts, the MAWP may be recalculated for a different extent of NDE in a supplement to the original Proof Test Report.

(3) The effect of the location of a weld joint may be evaluated and included in the Proof Test Report.

(f) A retest shall be allowed on a duplicate vessel or vessel part if errors or irregularities are obvious in the test results.

(g) In tests for determination of governing stresses, sufficient locations on the vessel shall be investigated to ensure that measurements are taken at the most critical areas. As a check that the measurements are being taken on the most critical areas, the Inspector may require a brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in (n) and (o) below. The surfaces shall be suitably cleaned before the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

NOTE: Strains should be measured as they apply to membrane stresses and to bending stresses within the range covered by UG-23(c).

(h) *Application of Pressure*. In the procedures given in (l), (n), and (o) below, the Displacement Measurement Test, the hydrostatic pressure in the vessel or vessel part shall be increased gradually until approximately one-half the anticipated working pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated maximum allowable working pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made, and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

(i) *Corrosion Allowance*. The test procedures in this paragraph give the maximum allowable working pressure for the thickness of material tested. The thickness of the pressure vessel that is to be proof tested should be the corroded thickness. When this is not practical and when the thickness as tested includes extra thickness as provided in UG-25, the maximum allowable working pressure at which the vessel shall be permitted to operate shall be determined by multiplying the maximum allowable working pressure obtained from the test by the ratio

$$(t-c)^n/t^n$$

where

c = allowance added for corrosion, erosion, and abrasion

n = 1 for curved surfaces such as parts of cylinders, spheres, cones with angle $\alpha \le 60$ deg; for stayed surfaces similar to those described in UW-19(b) and UW-19(c); and parts whose stress due to bending is ≤ 67% of the total stress

= 2 for flat or nearly flat surfaces, such as flat sides, flanges, or cones with angle $\alpha > 60$ deg (except for stayed surfaces noted above) unless it can be shown that the stress due to bending at the limiting location is <67% of the total stress

t = nominal thickness of the material at the weakest point

(j) *Determination of Yield Strength and Tensile Strength*

(1) For proof tests based on yielding, (l), (n), or (o) below, the yield strength (or yield point for those materials which exhibit that type of yield behavior indicated by a "sharp-kneed" portion of the stress–strain diagram) of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification. For proof tests based on bursting [see (m) below], the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

(2) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in (l), (m), (n), and (o) below for evaluation of proof test results to establish the maximum allowable working pressure.

(3) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimen shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen. When the sheet material is used, test specimens obtained from another piece cut from the same coil of sheet used in the proof tested component meet the requirements of this paragraph.

(k) *Maximum Allowable Working Pressure at Higher Temperatures*. The maximum allowable working pressure for vessels and vessel parts that are to operate at

temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following formula:

$$P_0 = P_t \frac{S}{S_2}$$

where

P_0 = maximum allowable working pressure at the design temperature
P_t = maximum allowable working pressure at test temperature
S = maximum allowable stress value at the design temperature, as given in the tables referenced in UG-23 but not to exceed S_2
S_2 = maximum allowable stress value for the material used in the test at test temperature as given in the tables referenced in UG-23

(l) Brittle-Coating Test Procedure

(1) Subject to the limitations of (a)(2)(-a) above, this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point (see SA-370, 13.1). The component parts that require proof testing shall be coated with a brittle coating in accordance with (g) above. Pressure shall be applied in accordance with (h) above. The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating, or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding, or if desired, at some lower pressure.

(2) The maximum allowable working pressure P in pounds per square inch (MPa) at test temperature for parts tested under this paragraph shall be computed by one of the following equations.

(-a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H \frac{S_y}{S_{y\ avg}}$$

(-b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following equations may be used to determine the maximum allowable working pressure:

(-1) For carbon steel meeting an acceptable Code specification, with a specified minimum tensile strength of not over 70,000 psi (480 MPa),

(U.S. Customary Units)

$$P = 0.5H \left(\frac{S_\mu}{S_\mu + 5000} \right)$$

(SI Units)

$$P = 0.5H \left(\frac{S_\mu}{S_\mu + 35} \right)$$

(-2) For any acceptable material listed in this Division,

$$P = 0.4H$$

where

H = hydrostatic test pressure at which the test was stopped, psi (kPa)
S_y = specified minimum yield strength at room temperature, psi (kPa)
$S_{y\ avg}$ = actual average yield strength from test specimens at room temperature, psi (kPa)
S_μ = specified minimum tensile strength at room temperature, psi (kPa)

When the formula in (-1) or (-2) above is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal.

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(m) Bursting Test Procedure

(1) This procedure may be used for vessels or vessel parts under internal pressure when constructed of any material permitted to be used under the rules of this Division. The maximum allowable working pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined. Alternatively, the test may be stopped at any pressure before rupture that will satisfy the requirements for the desired maximum allowable working pressure.

(2) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following equations:

(-a) parts constructed of materials other than cast materials:

$$P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu\ avg}} \quad or \quad P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu r}}$$

(-b) parts constructed of cast iron — see UCI-101; parts constructed of cast ductile iron — see UCD-101;

(-c) parts constructed of cast materials, except cast iron and ductile iron:

$$P = \frac{Bf}{4} \times \frac{S_\mu E}{S_{\mu\,\text{avg}}} \quad \text{or} \quad P = \frac{Bf}{4} \times \frac{S_\mu E}{S_{\mu r}}$$

where

B = bursting test pressure, or hydrostatic test pressure at which the test was stopped
E = efficiency of welded joint, if used (see Table UW-12)
f = casting quality factor as specified in UG-24
S_μ = specified minimum tensile strength at room temperature
$S_{\mu\,\text{avg}}$ = average actual tensile strength of test specimens at room temperature, or the tensile strength reported on the material test report when postweld heat treatment is not applied to the production component
$S_{\mu r}$ = maximum tensile strength of range of specification at room temperature

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(n) Strain Measurement Test Procedure

(1) Subject to limitations of (a)(2)(-a) above, this procedure may be used for vessels or vessel parts under internal pressure, constructed of any material permitted to be used under the rules of this Division. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts [see (g) above] by means of strain gages of any type capable of indicating incremental strains to 0.00005 in./in. (0.005%). It is recommended that the gage length be such that the expected maximum strain within the gage length does not exceed the expected average strain within the gage length by more than 10%. The strain gages and the method of attachment shall be shown by test to be reliable and the results documented for a range of strain values that is at least 50% higher than expected, when used with the material surface finish and configuration being considered. [See (e) above.]

(2) Pressure shall be applied as provided in (h) above. After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

(3) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H which will, by the formula, justify the desired working pressure, but shall not exceed the pressure at which the plotted points for the most highly strained gage line reaches the value given below for the material used:

(-a) 0.2% permanent strain for aluminum-base and nickel-base alloys;

(-b) 0.2% permanent strain for carbon low alloy and high alloy steels;

(-c) 0.5% strain under pressure for copper-base alloys.

(4) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following equations:

(-a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H\left(\frac{S_y}{S_{y\,\text{avg}}}\right)$$

(-b) If the actual average yield strength is not determined by test specimens,

$$P = 0.4H$$

where

H = hydrostatic test pressure at which the test was stopped in accordance with (3) above
S_y = specified minimum yield strength at room temperature
$S_{y\,\text{avg}}$ = actual average yield strength from test specimens at room temperature

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(o) Displacement Measurement Test Procedure

(1) Subject to the limitations of (a)(2)(-a) above, this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point (see SA-370, 13.1). Displacement shall be measured at the most highly stressed parts [see (g) above] by means of measuring devices of any type capable of measuring to 0.001 in. (0.02 mm). The displacement may be measured between two diametrically opposed reference points in a symmetrical structure, or between a reference point and a fixed base point. Pressure shall be applied as provided in (h) above.

(2) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be

taken to assure that the readings represent only displacements of the parts on which measurements are being made and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

(3) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

(4) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

(5) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following equations.

(-a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H\left(\frac{S_y}{S_{y\ avg}}\right)$$

(-b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following equations may be used to determine the maximum allowable working pressure.

(-1) For carbon steel, meeting an acceptable Code specification, with a specified minimum tensile strength of not over 70,000 psi (480 MPa),

(U.S. Customary Units)

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 5000}\right)$$

(SI Units)

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 35}\right)$$

(-2) For any acceptable material listed in this Division,

$$P = 0.4H$$

where

H = hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part tested
S_y = specified minimum yield strength at room temperature
$S_{y\ avg}$ = actual average yield strength from test specimens at room temperature
S_μ = specified minimum tensile strength at room temperature

When the formula in (-1) or (-2) above is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal. The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(p) Procedure for Vessels Having Chambers of Special Shape Subject to Collapse

(1) Pressure chambers of vessels, portions of which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by UG-28(i), shall withstand without excessive deformation a hydrostatic test of not less than three times the desired maximum allowable working pressure.

(2) The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

UG-102 TEST GAUGES (25)

UG-102.1 Connection of Pressure-Indicating Gauge. A pressure-indicating gauge shall be connected directly to the vessel or with a pressure line that does not include intermediate valves.

UG-102.2 Gauge Visibility. If the indicating gauge is not readily visible to the operator controlling the pressure applied, an additional indicating gauge shall be provided where it will be visible to the operator throughout the duration of the test. For large vessels, a recording gauge should be used in addition to an indicating gauge.

UG-102.3 Gauge Type. Indicating gauges may be dial or digital.

(a) Dial pressure-indicating gauges used in testing shall be graduated over a range of about 2 times the intended maximum test pressure, but in no case shall the range be less than $1\frac{1}{2}$ times nor more than 4 times the intended maximum test pressure.

(b) Digital pressure-indicating gauges having a wider range of pressure than described in (a) may be used provided readings have an equal or better degree of accuracy as obtained with dial pressure-indicating gauges.

UG-102.4 Gauge Calibration. As a minimum, all pressure-indicating gauges shall be calibrated against a standard deadweight tester or a calibrated master gauge, and shall be recalibrated any time there is reason to believe error exists.

(25) UG-103 NONDESTRUCTIVE TESTING

UG-103.1 Magnetic Particle Examination. Magnetic particle examination required by this Division shall be performed in accordance with Mandatory Appendix 6.

UG-103.2 Liquid Penetrant Examination. Liquid penetrant examination required by this Division shall be performed in accordance with Mandatory Appendix 8.

MARKING AND REPORTS

(25) UG-115 GENERAL

UG-115.1 Requirements. The marking and certification of all pressure vessels built under this Division shall comply with the requirements of UG-115.2 and with the requirements for marking and reports given in the applicable Parts of Subsections B, C, and D.

UG-115.2 Units of Measurement. The units of measurement for the following shall be either U.S. Customary units, SI units, or any local customary units (see U-4):

(a) Manufacturer's Data Reports

(b) Manufacturer's Certificates of Compliance (see UG-120)

(c) capacity certification of pressure relief devices

(d) marking or stamping of pressure vessels, pressure vessel parts, and pressure relief devices

(25) UG-116 REQUIRED MARKING

(a) Each pressure vessel shall be marked with the following:

(1) See below.

(-a) the official Certification Mark with the U Designator shown in Figure UG-116, sketch (a) on vessels inspected in accordance with the requirements in UG-90 through UG-97; or

(-b) the official Certification Mark with the UM Designator shown in Figure UG-116, sketch (b) on vessels constructed in accordance with the provisions in U-1(j); or

(-c) the official Certification Mark with the PRT VIII-1 Designator shown in Figure UG-116, sketch (c) on parts [see (h)]

(2) name of the Manufacturer of the pressure vessel preceded by the words "certified by"

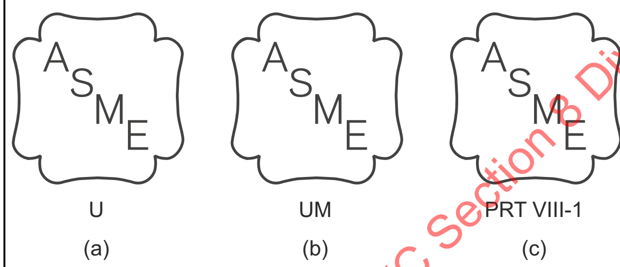
(3) maximum allowable working pressure[10,35] (internal or external[37]) ________at temperature ________

(4) minimum design metal temperature ________at maximum allowable working pressure[10] ________

(5) Manufacturer's serial number

(6) year built

Figure UG-116
Official Certification Mark to Denote the American Society of Mechanical Engineers' Standard



(7) the maximum designed steaming capacity for vessels in accordance with U-1(g)(1)

(b) See below.

(1) The type of construction used for the vessel shall be indicated directly under the Certification Mark by applying the appropriate designators and letter(s) as follows:

Type of Construction	Letter(s)
Tensile enhanced by heat treat (see UHT-115)	UHT
Layered (see ULW-115)	WL
Low temperature (see ULT-115)	ULT
Graphite (see UIG-116)	G
Cold stretched (see Mandatory Appendix 44, 44-7)	CS
Acrylic shell	A

(2) Vessels embodying a combination of types of construction shall be marked to indicate all of the types of construction used.

(c) When a vessel is intended for special service and the special requirements have been complied with [see UG-120(d)], the appropriate lettering shall be applied as listed below:

Special Service	Letter(s)
Lethal service	L
Unfired steam boiler	UB
Direct firing	DF

This lettering shall be separated by a hyphen and applied after the lettering of (b) above.

(d) The maximum allowable working pressure and temperature to be indicated on vessels embodying a combination of types of construction and material shall be based on the most restrictive detail of construction and material used.

(e) When radiographic or ultrasonic examination has been performed on a vessel in accordance with UW-11, marking shall be applied under the Certification Mark as follows:

(1) "RT 1" when all pressure-retaining butt welds, other than Category B and C butt welds associated with nozzles and communicating chambers that neither exceed NPS 10 (DN 250) nor $1^1/_8$ in. (29 mm) wall thickness [except as required by UHT-57(a)], satisfy the full radiography requirements of UW-11(a) for their full length; full radiography of the above exempted Category B and C butt welds, if performed, may be recorded on the Manufacturer's Data Report; or

(2) "RT 2" when the complete vessel satisfies the requirements of UW-11(a)(5) and when the spot radiography requirements of UW-11(a)(5)(-b) have been applied; or

(3) "RT 3" when the complete vessel satisfies the spot radiography requirements of UW-11(b); or

(4) "RT 4" when only part of the complete vessel has satisfied the radiographic requirements of UW-11(a) or where none of the markings "RT 1," "RT 2," or "RT 3" are applicable.

The extent of radiography and the applicable joint efficiencies shall be noted on the Manufacturer's Data Report.

(f) See below.

(1) The letters HT shall be applied under the Designators when the complete vessel has been postweld heat treated as provided in UW-10.

(2) The letters PHT shall be applied under the Designators when only part of the complete vessel has been postweld heat treated as provided in UW-10.

The extent of the postweld heat treatment shall be noted on the Manufacturer's Data Report.

(g) The Manufacturer shall have a valid Certificate of Authorization, and, with the acceptance of the Inspector, shall apply the Certification Mark to the vessel, which, together with the final certification [see U-1(j) and UG-120], shall indicate that all requirements of this Division have been met.

(1) Except as provided in (2) below, the Certification Mark shall be applied after the hydrostatic test or pneumatic test.

(2) The Certification Mark may be preapplied to a nameplate. The nameplate may be attached to the vessel after the final fabrication and examination sequence but before the hydrostatic tests or pneumatic test, provided the procedure for sequence of stamping is described in the Manufacturer's accepted Quality Control System.

(h) See below.

(1) Parts of vessels for which Partial Data Reports are required in UG-120(c) shall be marked by the parts Manufacturer, with a nameplate or stamping, with the following:

(-a) the official Certification Mark with, as applicable, either

(-1) the U Designator shown in Figure UG-116, sketch (a) above the word "PART"

(-2) the PRT VIII-1 Designator shown in Figure UG-116, sketch (c)

(-b) name of the Manufacturer of the part of the pressure vessel preceded by the words "certified by";

(-c) the Manufacturer's serial number.

When stamping with the Certification Mark with the PRT VIII-1 Designator, the word "PART" may be eliminated from the stamping.

Parts may be stamped with the Certification Mark without being pressure tested prior to shipment. If testing was not performed, this shall be indicated in the "Remarks" section of the Manufacturer's Partial Data Reports (see Nonmandatory Appendix W, Forms U-2 and U-2A).

This requirement does not apply to such items as handhole covers, manhole covers and their accessories. [See (k) below.]

(2) As an alternative to nameplates or stamping, parts 5 in O.D. and under may be marked with an identification acceptable to the Inspector and traceable to the Manufacturer's Partial Data Report Form U-2 or Form U-2A. Such marking shall be of a type that will remain visible until the parts are installed. The Certification Mark is not required.

(3) No accessory or part of a pressure vessel may be marked "ASME" or "ASME Std." unless so specified in this Division.

(4) A nameplate furnished with the Certification Mark on prefabricated or preformed parts may be removed from the completed pressure vessel if all of the following conditions are satisfied:

(-a) The nameplate interferes with further fabrication or service.

(-b) The Manufacturer of the completed vessel has agreement from the Authorized Inspector to remove the nameplate.

(-c) The removal of the nameplate shall be noted in the "Remarks" section of the vessel Manufacturer's Data Report.

(-d) The removed nameplate shall be destroyed.

(i) All required markings shall be located in a conspicuous place on the vessel, preferably near a manhole or handhole (see Nonmandatory Appendix M, M-3).

(j) Combination Units

(1) Those chambers included within the scope of this Division shall be marked. The marking shall include the name of each chamber (e.g., process chamber, jacket, tubes, channel) and its corresponding data. The markings shall be grouped in one location on the combination unit or applied to each individual chamber. Each detachable chamber shall be marked to identify it with the combination unit. When required, the marking shall include the following:

(-a) for differential pressure design, the maximum differential design pressure for each common element and the name of the higher pressure chamber [see UG-19(a)(2)]

(-b) for mean metal temperature design, the maximum mean metal design temperature for each common element [see UG-19(a)(3)].

(-c) for a common element adjacent to a chamber not included within the scope of this Division, the common element design conditions from that chamber

(2) It is recommended that the design conditions for those chambers not included within the scope of this Division be marked on the combination unit. The markings may be on the applicable chamber or grouped as described in (1), provided they are not included in the markings covered by the Certification Mark.

(k) Removable pressure parts shall be permanently marked in a manner to identify them with the vessel or chamber of which they form a part. This does not apply to manhole covers, handhole covers, and their accessory parts, provided the marking requirements of UG-11 are met.

(25) UG-117 CERTIFICATES OF AUTHORIZATION AND CERTIFICATION MARKS

(a) A Certificate of Authorization to use the Certification Mark with the U, UM, or PRT VIII-1 Designator shown in Figure UG-116 will be granted by the Society pursuant to the provisions of the following paragraphs. Stamps for applying the Certification Mark shall be obtained from the Society. For those items to be marked with the UM Designator, a Certified Individual meeting the current requirements of ASME QAI-1 shall provide oversight to ensure that each use of the UM Designator is in accordance with the requirements of this Division. In addition, each use of the UM Designator is to be documented on the Certificate of Compliance (see Nonmandatory Appendix W, Form U-3, Form U-3A, or Form U-3P).

(1) Requirements for the Certified Individual (CI). The CI shall

(-a) be qualified in accordance with ASME CA-1 and the requirements of this Division

(-b) have the following qualifications as a minimum:

(-1) knowledge of the requirements of this Division for the application of the Certification Mark with the appropriate designator;

(-2) knowledge of the Manufacturer's or Assembler's quality program;

(-3) training commensurate with the scope, complexity, or special nature of the activities to which oversight is to be provided.

(-c) have a record, maintained and certified by the Manufacturer or Assembler, containing objective evidence of the qualifications of the CI and the training program provided.

(2) Duties of the Certified Individual (CI). The CI shall

(-a) verify that each item to which the Certification Mark is applied meets all applicable requirements of this Division;

(-b) sign the appropriate Certificate of Compliance/Conformance (see Nonmandatory Appendix W, Form U-3, Form U-3A, or Form U-3P) as appropriate prior to release of control of the item.

(3) Certificate of Compliance/Conformance (Forms U-3, Form U-3A, Form U-3P)

(-a) The appropriate Certificate of Conformance shall be filled out by the Manufacturer or Assembler and signed by the Certified Individual.

(-b) The Manufacturer's or Assembler's written quality control program shall include requirements for completion of Certificates of Conformance forms and retention by the Manufacturer or Assembler for a minimum of 5 yr.

(b) Application for Certificate of Authorization. Any organization desiring a Certificate of Authorization shall apply to ASME in accordance with the certification process of ASME CA-1. Authorization to use Certification Marks maybe granted, renewed, suspended, or withdrawn as specified in ASME CA-1. Applicants for a UM Certificate of Authorization must already hold an S or U Certificate.

(c) Issuance of Authorization. Certificate of Authorization shall be issued in accordance with ASME CA-1 (see www.asme.org/shop/certification-accreditation).

*(d) Designated Oversight.*The Manufacturer shall comply with the requirements of ASME CA-1 for designated oversight by use of an Authorized Inspection Agency or Certified Individual, as applicable.

(e) Quality Control System. Any Manufacturer holding or applying for a Certificate of Authorization shall demonstrate a quality control program that meets the requirements of ASME CA-1 and establishes that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), inspection of vessel and vessel parts (by the Authorized Inspector or Certified Individual, as applicable), pressure testing, and certification, will be met. The Quality Control System shall be in accordance with the requirements of Mandatory Appendix 10.

(f) Evaluation of the Quality Control System. The issuance or renewal of a Certificate of Authorization is based upon ASME's evaluation and approval of the Quality Control System, and shall be in accordance with ASME CA-1. Before issuance or renewal of a Certificate of Authorization for use of the U, UM, or PRT VIII-1 Designator, the Manufacturer's facilities and organization are subject to a joint review by a representative of the Authorized Inspection Agency and an individual certified as an ASME designee who is selected by the concerned legal jurisdiction.

Certificates of Authorization are valid for the period given in ASME CA-1. UM Certificates are valid for 1 yr, but reviews after the first and second years of each 3-yr period are performed by the Authorized Inspection Agency only and shall include at a minimum an Authorized Inspector Supervisor.

Any changes made to the Quality Control System shall be made and accepted in accordance with the requirements specified in ASME CA-1. For Manufacturers of mass-produced pressure vessels,[38] acceptance of these changes by the ASME designee is also required.

For those areas where there is no jurisdiction or where a jurisdiction does not choose to select an ASME designee to review a vessel or vessel parts Manufacturer's facility, that function shall be performed by an ASME designee selected by ASME. Where the jurisdiction is the Manufacturer's Inspection Agency, the joint review and joint report shall be made by the jurisdiction and an ASME designee selected by ASME.

(g) Code Construction Before Receipt of Certificate of Authorization. When used to demonstrate the Manufacturer's Quality Control System, a Manufacturer may start fabricating Code items before receipt of a Certificate of Authorization to use a Certification Mark under the conditions specified in ASME CA-1.

UG-118 METHODS OF MARKING

(a) The required marking shall be applied to the vessel by one of the following methods:

(1) nameplate as provided in UG-119

(2) stamped directly on the vessel under the following conditions:

(-a) Unless the requirements of (-b) or (-c) are met, such stamping shall not be used on vessels constructed of steel plates less than $\frac{1}{4}$ in. (6 mm) thick or of nonferrous plates less than $\frac{1}{2}$ in. (13 mm) thick but may be used on vessels constructed of thicker plates.

(-b) For Ferrous Materials

(-1) The materials shall be limited to P-No. 1, Group Nos. 1 and 2.

(-2) The minimum nominal plate thickness shall be 0.1875 in. (5 mm), or the minimum nominal pipe wall thickness shall be 0.154 in. (4 mm).

(-3) The minimum design metal temperature shall be no colder than −20°F (−29°C).

(-c) For Nonferrous Materials

(-1) The materials shall be limited to aluminum as follows: SB-209 alloys 3003, 5083, 5454, and 6061; SB-241 alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 alloys 3003, 5083, and 6061.

(-2) The minimum nominal plate thickness shall be 0.249 in. (6.30 mm), or the minimum nominal pipe thickness shall be 0.133 in. (3.38 mm).

(3) electrochemically etched, including the Certification Mark, directly on the vessel under the following conditions:

(-a) The electrochemically etched marking is acceptable to the user as indicated in the User's Design Requirements per Nonmandatory Appendix KK, or equivalent.

(-b) The material of construction shall be limited to high alloy steels and nonferrous materials.

(-c) The process controls for electrochemical etching shall be described in the Quality Control System and shall be acceptable to the Authorized Inspector. The process controls shall be established so that it can be demonstrated that the characters will be at least 0.004 in. (0.102 mm) deep.

(-d) The external vessel-surface condition where electrochemical etching is acceptable shall be clean, uncoated, and unpainted.

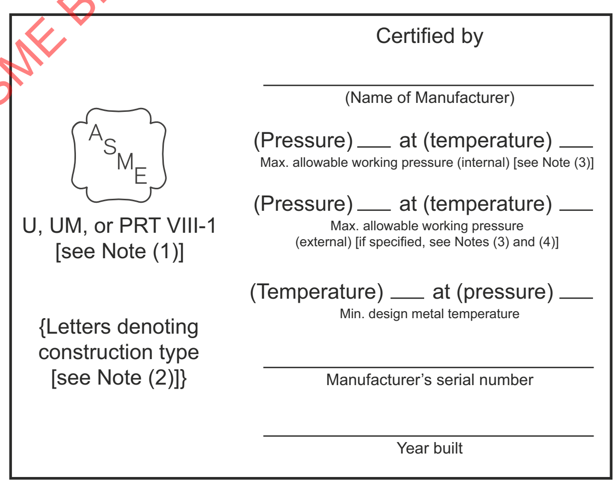
(-e) The electrochemical etching shall not result in any detrimental effect to the materials of the vessel.

(b) Stamped or electrochemically etched letters and figures shall be in characters not less than $\frac{5}{16}$ in. (8 mm) high. The character size may be reduced as shown in the following table for small diameter vessels with space limitations:

Nominal Outside Vessel Diameter		Character Size,
Min., in. (mm)	Max., in. (mm)	Min., in. (mm)
...	$3\frac{1}{2}$ (89)	$\frac{1}{8}$ (3)
>$3\frac{1}{2}$ (>89)	$4\frac{1}{2}$ (114)	$\frac{3}{16}$ (5)
>$4\frac{1}{2}$ (>114)	$6\frac{5}{8}$ (168)	$\frac{1}{4}$ (6)

(c) Stamping or electrochemical etching shall be arranged substantially as shown in Figure UG-118 when space permits and shall be located in a conspicuous place on the vessel [see UG-116(i)].

Figure UG-118 Form of Stamping (25)



GENERAL NOTE: Information within parentheses, brackets, or braces is not part of the required marking. Phrases identifying data may be abbreviated; minimum abbreviations shall be MAWP, MDMT, S/N, FV, and year, respectively. See ASME PTB-4 for sample Nameplate markings.

NOTES:

(1) See UG-116(a)(1)(-a), UG-116(a)(1)(-b), and UG-116(a)(1)(-c).

(2) See UG-116(b)(1), UG-116(c), UG-116(e), UG-116(f), and UG-116(h)(1)(-a).

(3) For cases where the MAWP (internal) and MAWP (external) values have the same designated coincident temperature, the values may be combined on a single line as follows:

$$P_{int}/FV \text{ (psi) at Temp (°F)}$$

(4) The maximum allowable working pressure (external) is required only when specified as a design condition.

(25) UG-119 NAMEPLATES

(a) Nameplates shall be used on vessels except when markings are directly applied in accordance with UG-118. Nameplates shall be metal suitable for the intended service and shall bear the markings called for in UG-116. The marking arrangement shall be substantially as shown in Figure UG-118. Required nameplates shall be located in a conspicuous place on the vessel.

(b) The nameplate thickness shall be sufficient to resist distortion due to the application of the marking and to be compatible with the method of attachment. The nameplate nominal thickness shall not be less than 0.020 in.

(c) Nameplates shall have permanent, legible markings produced by either casting, etching, embossing, debossing, stamping, engraving, or laser annealing.

(1) The required markings on a nameplate shall be in characters not less than $^5/_{32}$ in. (4 mm) high, except that characters for pressure relief device markings may be smaller.

(2) Characters produced by processes other than laser annealing shall be either indented or raised at least 0.004 in. (0.10 mm).

(3) Laser annealing is allowed only on stainless steel and aluminum.

(4) No coating that obscures the laser annealing marking shall be allowed.

(5) The Certification Mark shall be stamped on the nameplate unless process controls for mechanical etching or laser annealing by the Manufacturer of the certified vessel have been described in the accepted Quality Control System and approved by the Authorized Inspector.

(d) The nameplate may be marked before it is affixed to the vessel, in which case the Manufacturer shall ensure that the nameplate with the correct marking has been applied to the proper vessel, and the Inspector shall verify that this has been done.

(e) The nameplate shall be attached to the vessel or to a pad, bracket, or structure that is welded, brazed, soldered, or attached with mechanical fasteners directly to the vessel. Mechanical fasteners shall be of a material and design that is compatible with the vessel, bracket materials, and the vessel service. After installation of the pad, bracket, or structure, the heads of the fasteners shall be welded, brazed, or soldered to the pad, bracket, or structure that supports the nameplate. The nameplate shall be located within 30 in. (760 mm) of the vessel. Removal shall require the willful destruction of the nameplate, or its attachment system. (See Nonmandatory Appendix M, M-3.)

(1) Nameplates may be attached either by welding, brazing, or soldering.

(2) Nameplates may be attached by tamper-resistant mechanical fasteners of suitable metal construction.

(3) Nameplates may be attached with pressure-sensitive acrylic adhesive systems provided that, in addition to the requirements of this paragraph, those of Mandatory Appendix 18 are met.

(f) An additional nameplate in accordance with (a) through (d) may be installed on the skirt, supports, jacket, or other permanent attachment to a vessel. All data on the additional plate, including the Certification Mark with the Designator, shall be as required for the mandatory nameplate. The marking need not be witnessed by the Inspector. The additional nameplate shall be marked: "DUPLICATE."

(g) When a nameplate is employed, the Manufacturer's name or identifying trademark, and vessel serial number (or National Board Number, if applicable,) may also be marked directly on the vessel in close proximity to the nameplate attachment. The marking shall be of a visible permanent type that is not detrimental to the vessel, and its location shall be indicated on the Data Report.

(1) If the thickness limitations of UG-118 preclude marking directly on the vessel shell or heads, it may be applied to the skirt, supports, jacket, or other permanent attachment to the vessel.

UG-120 DATA REPORTS (25)

(a) A Data Report shall be filled out on Nonmandatory Appendix W, Form U-1, Form U-1A, or Form U-1P by the Manufacturer and shall be signed by the Manufacturer and the Inspector for each pressure vessel marked with the Certification Mark with the U Designator.

(1) Same day production of vessels may be reported on a single Form, provided all of the following requirements are met:

(-a) vessels must be identical;

(-b) vessels must be manufactured for stock or for the same user or the user's designated agent;

(-c) serial numbers must be in uninterrupted sequence; and

(-d) the Manufacturer's written Quality Control System includes procedures to control the development, distribution, and retention of the Data Reports.

(2) For guidance in preparing the Manufacturer's Data Report Forms, see Nonmandatory Appendix W. Horizontal spacing for information on each line may be altered as necessary. All information must be addressed; however, footnotes described in the "Remarks" block are acceptable, e.g., for multiple cases of "none" or "not applicable."

(3) The Manufacturer shall

(-a) furnish a copy of the Manufacturer's Data Report to the user and, upon request, to the Inspector:

(-b) submit a copy of the Manufacturer's Data Report to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed, where required by law;

(-c) keep a copy of the Manufacturer's Data Report on file in a safe repository for at least 3 years.

In lieu of (-c) above, the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229. Where acceptable to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed, the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors in lieu of (-b) above.

(4) A Manufacturer's Certificate of Compliance on Nonmandatory Appendix W, Form U-3, Form U-3A, or Form U-3P shall be completed and signed by the Manufacturer for each pressure vessel marked with the Certification Mark with the UM Designator. This Certificate shall be maintained by the Manufacturer for 5 years and a copy made available upon request, or the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229. Where acceptable to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed, the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors. Identical vessels up to 1 day's production may be recorded on a single Certificate of Compliance.

(b) Combination Units

(1) Those chambers included within the scope of this Division shall be described on the same Data Report. This includes the following, as applicable:

(-a) for differential pressure design, the maximum differential design pressure for each common element and the name of the higher pressure chamber [see UG-19(a)(2)]

(-b) for mean metal temperature design, the maximum mean metal design temperature for each common element [see UG-19(a)(3)]

(-c) for a common element adjacent to a chamber not included within the scope of this Division, the common element design conditions from that chamber

(-d) for limiting pressure tests, the common element subject to collapse due to external pressure and its limiting test pressure [see UG-99(e)(1)(-c) or UG-100(d)(1)(-c)]

(2) It is recommended that those chambers not included within the scope of this Division be described in the "Remarks" section of the Data Report.

(3) For a fixed tubesheet heat exchanger, Nonmandatory Appendix W, Form U-5 shall be filled out with the information required by UHX-19.3.2, signed by the Manufacturer and Inspector, and included with the Manufacturer's Data Report.

(c) Partial Data Reports

(1) Data Reports to document the construction activities of pressure vessel parts requiring inspection under this Division that are furnished by a parts Manufacturer other than the Manufacturer responsible for the completed vessel shall be executed on the applicable Partial Data Report, Nonmandatory Appendix W, Form U-2 or Form U-2A, by the parts Manufacturer and Inspector in accordance with the requirements of this Division. The Manufacturer's Partial Data Report shall be forwarded, in duplicate, to the Manufacturer of the completed vessel [see U-2(b)]. Nonmandatory Appendix W, Form U-2A may be used for this purpose, provided all the applicable information is recorded on this Form; otherwise Nonmandatory Appendix W, Form U-2 shall be used. These Partial Data Reports, together with the completed vessel's inspection, shall be the final Inspector's authority to witness the application of a Certification Mark to the vessel [see UG-90.3]. When Nonmandatory Appendix W, Form U-2 or Form U-2A is used, it shall be attached to the associated Nonmandatory Appendix W, Form U-1, Form U-1A, or Form U-1P by the Manufacturer of the vessel to be marked with the Certification Mark. Manufacturers and Assemblers of parts who do not perform or assume any design responsibility for the parts they manufacture shall identify on the Partial Data Report the organization responsible for the design of the part. As is applicable in (-a), a parts Manufacturer that performs no design function shall state under "Remarks," "User Specified Part, No Design Performed."

(-a) Data Reports for those parts of a pressure vessel which are furnished by a parts Manufacturer to the user of an existing Code vessel as replacement or repair parts shall be executed on Nonmandatory Appendix W, Form U-2 or Form U-2A by the parts Manufacturer and the Inspector in accordance with the requirements of this Division. A copy of the parts Manufacturer's Partial Data Report shall be furnished to the user or the user's designated agent and maintained in accordance with (a) above.

(-b) The parts Manufacturer shall indicate under "Remarks" the extent to which the Manufacturer has performed any or all of the design functions. When the parts Manufacturer performs only a portion of the design, the parts Manufacturer shall state which portions of the design were performed.

(-c) Same day production of vessel parts may be reported on a single Nonmandatory Appendix W, Form U-2 or Form U-2A, provided all of the following are met:

(-1) vessel parts shall be identical;

(-2) Manufacturer's serial numbers must be in uninterrupted sequence; and

(-3) The Manufacturer's written Quality Control System includes procedures to control the development, distribution, and retention of the Partial Data Reports.

(-d) For guidance in preparing Partial Data Reports, see Nonmandatory Appendix W.

(-e) Manufacturers with multiple locations under the operational control of a single organization[39], each location with its own Certificate of Authorization, may transfer welded or brazed pressure vessel parts, or completely welded pressure vessels that have not been pressure tested or received final inspection, from one location to another without Partial Data Reports, provided the Quality Control System describes the method of identification, transfer, and receipt of the parts. These methods shall include the following requirements:

(-1) Identification requirements shall include details of the specific marking to be applied. Identification shall be on each part and shall be legible, permanent, and not detrimental to the part.

(-2) The Certificate Holder shall have a transmittal form that is included with each transfer. It shall list all items with corresponding identification number, with indication that the items do not contain the Certification Mark. This form shall be signed by the Certificate Holder.

(-3) The receiving location shall inspect each item upon receipt.

(-4) The Manufacturer of the completed vessel shall retain all transfer forms as part of the vessel records; see Mandatory Appendix 10, 10-13.

(-f) For cases in which a Manufacturer has multiple locations that include both shop and field locations, and the field assembly of a vessel is completed by one Manufacturer's location that is different from the part Manufacturer's location(s), the name of the Manufacturer responsible for field assembly shall be shown on Line 1 of the Manufacturer's Data Report. The Manufacturer responsible for field assembly shall complete and sign both the Shop and Field portions of the Manufacturer's Data Report.

(2) A Manufacturer with multiple locations, each holding its own Certificate of Authorization, may transfer pressure vessel parts from one of its locations to another without Partial Data Reports, provided the Quality Control System describes the method of identification, transfer, and receipt of the parts. For cases in which a Manufacturer has multiple locations that include both shop and field locations, and the field assembly of the vessel is completed by one Manufacturer's location that is different from the part Manufacturer's location(s), the name of the Manufacturer responsible for field assembly shall be shown on Line 1 of the Manufacturer's Data Report. The Manufacturer responsible for field assembly shall complete and sign both the Shop and Field portions of the Manufacturer's Data Report.

(d) This Division, in paragraphs such as UW-2, UF-1, UF-32(b), UB-1, UB-22, UCS-66, UNF-56, UHA-51, UCL-27, and UHT-6, establishes special requirements to qualify a vessel for certain "special services." (Paragraphs, such as UW-2, prohibit certain types of construction or materials in some special services.) The special services to which special requirements are applicable are classified as follows:

(1) lethal service [for example, see UW-2(a)];

(2) services below certain temperatures (for example, see UW-2(b), UCS-65, UHA-51, and UHT-6);

(3) unfired steam boiler [for example, see UW-2(c)];

(4) direct firing [for example, see UW-2(d)].

When a vessel is intended for such special services, the special service and the paragraphs of special requirements complied with shall be indicated on the Data Reports.

(e) Pressure-retaining covers and their attaching bolting and nuts shall be listed in the "Remarks" section of the Manufacturer's Data Report or on an attached Nonmandatory Appendix W, Form U-4 when required. The minimum information shall include the material specification, material grade, size, and thread designation.

(f) An unfired steam boiler, referenced in U-1(g)(1), shall have its maximum designed steaming capacity recorded in the "Remarks" section of the Data Report.

(g) For sample forms and guidance in their preparation, see Nonmandatory Appendix W.

OVERPRESSURE PROTECTION

In the 2021 Edition of Division 1, pressure relief device requirements were transferred from UG-125 through UG-140 to Section XIII, and the remaining Division 1 overpressure protection requirements were restructured within UG-150 through UG-156. A complete cross-reference list of the changes between the 2019 and 2021 Editions is available in Nonmandatory Appendix PP of the 2021 Edition.

UG-150 GENERAL REQUIREMENTS

(a) UG-150 through UG-155 provide the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths, and overpressure protection by system design. It establishes the type, quantity and settings of acceptable pressure relief devices and relieving capacity requirements including maximum allowed relieving pressures. Unless otherwise specified, the required pressure relief devices shall be constructed, capacity certified, and bear the ASME Certification Mark in accordance with Section XIII. UG-156 provides requirements for installation of pressure relief devices.

(b) Other than unfired steam boilers, all pressure vessels within the scope of this Division, regardless of size or pressure, shall be provided with overpressure protection in accordance with the requirements of UG-150 through UG-156.

(c) Unfired steam boilers shall be provided with pressure relief devices in accordance with the requirements of UG-150 through UG-156.

(d) Unfired steam boilers shall be equipped with pressure relief devices required by Section I to the extent that they are applicable to the service of the particular installation.

(e) Pressure relief devices for vessels that are to operate completely filled with liquid shall be designed for liquid service.

(f) Unless otherwise defined in this Division, the definitions relating to pressure relief devices in Section XIII shall apply.

(25) UG-151 RESPONSIBILITIES

(a) It is the user's or the user's designated agent's responsibility to determine the required relief rate, to size and select the device, and to design the relief system.

(b) It is the responsibility of the user to ensure that the required overpressure protection system is properly installed prior to initial operation.

(c) If a pressure relief device(s) is to be installed, it is the responsibility of the user or the user's designated agent to size and select the pressure relief device(s) based on its intended service. Intended service considerations shall include, but not necessarily be limited to, the following:

(1) normal operating and upset conditions
(2) fluids
(3) fluid phases

(d) The overpressure protection system need not be supplied by the vessel Manufacturer.

(e) If a pressure vessel is provided with more than one MAWP per UG-98(c) or para. UIF-5, it is the user's responsibility to provide overpressure protection per this Division for the vessel operation corresponding to each of the MAWPs and coincident temperatures.

(25) UG-152 DETERMINATION OF PRESSURE RELIEVING REQUIREMENTS

(a) It is the user's or the user's designated agent's responsibility to identify all potential overpressure scenarios and the method of overpressure protection used to mitigate each scenario.

(b) The aggregate capacity of the pressure relief devices connected to any vessel or system of vessels for the release of a liquid, air, steam, or other vapor shall be sufficient to carry off the maximum quantity that can be generated or supplied to the attached equipment without permitting a rise in pressure within the vessel of more than that specified in UG-153.

(c) Vessels connected together by a system of adequate piping not containing valves that can isolate any vessel, and those containing valves in compliance with Section XIII Nonmandatory Appendix B, may be considered as one unit in figuring the required relieving capacity of pressure relief devices to be furnished.

(d) Heat exchangers and similar vessels shall be protected with a pressure relief device of sufficient capacity to avoid overpressure in case of an internal failure.

(e) The rated pressure-relieving capacity of a pressure relief valve for other than steam, water, or air shall be determined by the method of conversion given in Section XIII, Mandatory Appendix IV.

(f) The relieving capacity of a pressure relief device for compressible fluids may be prorated at any relieving pressure greater than $1.10p$, as permitted under UG-153, by applying a multiplier to the official relieving capacity as follows:

(U.S. Customary Units)

$$\frac{P + 14.7}{1.10p + 14.7}$$

(SI Units)

$$\frac{P + 101}{1.10p + 101}$$

where

P = relieving pressure, psig (kPa gage)
p = set pressure, psig (kPa gage)

For steam pressures above 1,500 psig (10 MPa gage), the above multiplier is not applicable. For steam valves with relieving pressures greater than 1,500 psig (10 MPa gage) and less than or equal to 3,200 psig (22.1 MPa gage), the capacity at relieving pressures greater than $1.10p$ shall be determined using the equation for steam and the correction factor for high pressure steam in Section XIII, 9.7.6.4 with the permitted absolute relieving pressure and the coefficient K for that valve design.

UG-153 OVERPRESSURE LIMITS (25)

(a) Other than unfired steam boilers, when a pressure relief device is provided, it shall prevent the pressure from rising more than 10% or 3 psi (20 kPa), whichever is greater, above the maximum allowable working pressure, except as permitted in (1) through (3) and (c). (See UG-155 for pressure settings.)

(1) When multiple pressure relief devices are provided and set in accordance with UG-155(a), they shall prevent the pressure from rising more than 16% or 4 psi (30 kPa), whichever is greater, above the maximum allowable working pressure.

(2) When a pressure vessel can be exposed to fire or other unexpected sources of external heat, the pressure relief device(s) shall be capable of preventing the pressure from rising more than 21% above the maximum allowable working pressure. Supplemental pressure relief devices shall be installed to protect against this source of excessive pressure if the pressure relief devices used to satisfy the capacity requirements of (a) and (1) above have insufficient capacity to provide the required protection. See Nonmandatory Appendix M, M-13 for cases where the metal temperature due to fire or other sources of external heat can cause vessel failure prior to reaching the MAWP.

(3) Pressure relief devices, intended primarily for protection against exposure of a pressure vessel to fire or other unexpected sources of external heat installed

on vessels having no permanent supply connection and used for storage at ambient temperatures of nonrefrigerated liquefied compressed gases,[40] are excluded from the requirements of (1) and (2), provided

(-a) the pressure relief devices are capable of preventing the pressure from rising more than 20% above the maximum allowable working pressure of the vessels

(-b) the set pressure marked on these devices do not exceed the maximum allowable working pressure of the vessels

(-c) the vessels have sufficient ullage to avoid a liquid-full condition

(-d) the maximum allowable working pressure of the vessels on which these pressure relief devices are installed is greater than the vapor pressure of the stored liquefied compressed gas at the maximum anticipated temperature[41] that the gas will reach under atmospheric conditions

(-e) pressure relief valves used to satisfy these provisions also comply with the requirements of UG-155(e); Section XIII, 3.9(e)(5)(-a); and Section XIII, Table 9.7.2-1 for fire.

(b) For vessels that use overpressure protection by system design, the overpressure limits shall be per UG-154(e).

(c) The aggregate capacity of the open flow paths, or vents, shall be sufficient to prevent overpressure in excess of those specified in (a). When the MAWP is 15 psi (105 kPa) or less, in no case shall the pressure be allowed to rise more than 21% above the MAWP.

(25) UG-154 PERMITTED PRESSURE RELIEF DEVICES AND METHODS

Protection against overpressure shall be provided by pressure relief devices, open flow paths, or system design or a combination thereof in accordance with this paragraph.

(a) Pressure Relief Valves

(1) Pressure relief valves bearing the ASME Certification Mark with the UV Designator in accordance with Section XIII may be used. Pressure relief valves shall be of the direct spring-loaded or pilot-operated type.

(2) Pressure relief valves certified for a steam discharging capacity under the provisions of Section I and bearing the ASME Certification Mark with the V Designator for safety valves may be used on pressure vessels constructed to this Division. The rated capacity in terms of other fluids shall be determined by the method of conversion given in Section XIII, Mandatory Appendix IV. (See Section XIII, 9.2.3.)

(b) Nonreclosing Pressure Relief Devices

(1) Rupture disks bearing the ASME Certification Mark with the UD Designator in accordance with Section XIII may be used as the sole pressure-relieving device for overpressure protection.

NOTE: When rupture disk devices are used, it is recommended that the design pressure of the vessel be sufficiently above the intended operating pressure to provide sufficient margin between operating pressure and rupture disk bursting pressure to prevent premature failure of the rupture disk due to fatigue or creep.

Application of rupture disk devices to liquid service should be carefully evaluated to ensure that the design of the rupture disk device and the dynamic energy of the system on which it is installed will result in sufficient opening of the rupture disk.

(2) A pin device bearing the ASME Certification Mark with the UD Designator in accordance with Section XIII may be used as the sole pressure-relieving device for overpressure protection

(3) A spring-actuated non-reclosing pressure relief device bearing the ASME Certification Mark with the UD Designator in accordance with Section XIII may be used as the sole pressure-relieving device for overpressure protection.

(c) Combination of Devices

(1) The following combinations of devices may be used, provided they meet the requirements of Section XIII, Part 8:

(-a) a rupture disk device installed between a pressure relief valve and the vessel

(-b) a rupture disk device installed on the outlet side of a pressure relief valve that is opened by direct action of the pressure in the vessel

(-c) a pin device installed between a pressure relief valve and the vessel

(2) A pin device shall not be installed on the outlet side of a pressure relief valve that is opened by direct action of the pressure in the vessel.

NOTE: Use of nonreclosing pressure relief devices of some types may be advisable on vessels containing substances that may render a pressure relief valve inoperative, such as where a loss of valuable material by leakage should be avoided or where contamination of the atmosphere by leakage of noxious fluids must be avoided. The use of rupture disk devices may also be advisable when very rapid rates of pressure rise may be encountered.

(d) Open Flow Paths

(1) Flow paths or vents, open directly or indirectly to the atmosphere may be used as the sole pressure relieving device on a vessel.

(2) The calculated capacity of any pressure relief system may be determined by analyzing the total system resistance to flow. This analysis shall take into consideration the flow resistance of the piping and piping components including the exit nozzle on the vessels, elbows, tees, reducers, and valves. The calculation shall be made using accepted engineering practices for determining fluid flow through piping systems. This calculated relieving capacity shall be multiplied by a factor of 0.90 or less to allow for uncertainties inherent in this method.

(e) Overpressure Protection by System Design

Overpressure protection by system design in accordance with Section XIII, Part 13 is permitted.

(1) For vessels with overpressure protection by system design where the pressure is self-limited at or below the vessel MAWP, (see Section XIII, 13.2), there shall be no credible overpressure scenario in which the pressure exceeds the maximum allowable working pressure (MAWP) of the pressurized equipment at the coincident temperature.

(2) For vessels with overpressure protection by system design where the pressure is not self-limited at or below the vessel MAWP, (see Section XIII, 13.3), there shall be no credible overpressure scenario in which the pressure exceeds 116% of the MAWP times the ratio of the allowable stress value at the temperature of the overpressure scenario to the allowable stress value at the vessel design temperature. The overpressure limit shall not exceed the vessel test pressure.

(3) For either case, the user shall provide a User's Design Requirements Form, or document with equivalent information, stating that the vessel will be protected by overpressure protection by system design. See U-2(a)(2)(-b).

(4) The Manufacturer shall state on the Manufacturer's Data Report that the vessel is protected from overpressure by system design.

(25) UG-155 PRESSURE SETTINGS AND PERFORMANCE REQUIREMENTS

(a) When a single pressure relief device is used, the set pressure marked on the device shall not exceed the maximum allowable working pressure of the vessel. When the required capacity is provided in more than one pressure relief device, only one pressure relief device need be set at or below the maximum allowable working pressure, and the additional pressure relief devices may be set to open at higher pressures but in no case at a pressure higher than 105% of the maximum allowable working pressure, except as provided in (b).

(b) For pressure relief devices permitted in UG-153(a)(2) as protection against excessive pressure caused by exposure to fire or other sources of external heat, the device marked set pressure shall not exceed 110% of the maximum allowable working pressure of the vessel. If such a pressure relief device is used to meet the requirements of both UG-153(a) and UG-153(a)(2), the device marked set pressure shall not be over the maximum allowable working pressure.

(c) The pressure relief device set pressure shall include the effects of static head and constant back pressure.

(d) The set pressure tolerance for pressure relief valves shall not exceed ±2 psi (15 kPa) for pressures up to and including 70 psi (500 kPa) and ±3% for pressures above 70 psi (500 kPa), except as covered in (e).

(e) The set pressure tolerance of pressure relief valves which comply with UG-153(a)(3) shall be within −0%, +10%.

(f) The burst pressure tolerance for rupture disk devices at the specified disk temperature shall not exceed ±2 psi (15 kPa) of marked burst pressure up to and including 40 psi (300 kPa) and ±5% of marked burst pressure above 40 psi (300 kPa).

(g) The set pressure tolerance for pin devices shall not exceed ±2 psi (15 kPa) of marked set pressure up to and including 40 psi (300 kPa) and ±5% of marked set pressures above 40 psi (300 kPa) at specified pin temperature.

(h) The tolerance of spring-actuated non-reclosing pressure relief devices opening point shall not exceed ±5%.

UG-156 INSTALLATION

(a) Pressure relief devices shall be constructed, located, and installed so that they are readily accessible for testing, inspection, replacement, and repair and so that they cannot be readily rendered inoperative (see Nonmandatory Appendix M).

(b) The pressure relief devices required in UG-150(b) and UG-150(c) need not be installed directly on a pressure vessel when either of the following conditions apply:

(1) The source of pressure is external to the vessel and is under such positive control that the pressure in the vessel cannot exceed the maximum allowable working pressure at the operating temperature except as permitted in UG-153(a) (see UG-98), or under the conditions set forth in Nonmandatory Appendix M.

(2) There are no intervening stop valves between the vessel and the pressure relief device or devices, except as permitted under (g).

NOTE: Pressure-reducing valves and similar mechanical or electrical control instruments, except for pilot-operated pressure relief valves as permitted in UG-154(a), are not considered as sufficiently positive in action to prevent excess pressures from being developed.

(c) Pressure relief devices intended for relief of compressible fluids shall be connected to the vessel in the vapor space above any contained liquid or to piping connected to the vapor space in the vessel which is to be protected. Pressure relief devices intended for relief of liquids shall be connected below the liquid level. Alternative connection locations are permitted, depending on the potential vessel overpressure scenarios and the type of relief device selected, provided the requirements of UG-151(b) and UG-153(a) are met.

(d) The opening through all pipe, fittings, and nonreclosing pressure relief devices (if installed) between a pressure vessel and its pressure relief valve shall have at least the area of the pressure relief valve inlet. The characteristics of this upstream system shall be such that the pressure drop will not reduce the relieving capacity below that required or adversely affect the proper operation of the pressure relief valve.

(e) The opening in the vessel wall shall be designed to provide unobstructed flow between the vessel and its pressure relief device (see Nonmandatory Appendix M).

(f) When two or more required pressure relief devices are placed on one connection, the inlet internal cross sectional area of this connection shall be either sized to avoid restricting flow to the pressure relief devices or made at least equal to the combined inlet areas of the safety devices connected to it. The flow characteristics of the upstream system shall satisfy the requirements of (d) and (e) (see Nonmandatory Appendix M).

(g) There shall be no intervening stop valves between the vessel and its pressure relief device or devices, or between the pressure relief device or devices and the point of discharge, except

(1) when these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure-relieving capacity provided by the unaffected pressure relief devices below the required relieving capacity, or

(2) under conditions set forth in Section XIII, Nonmandatory Appendix B

(h) The pressure relief devices on all vessels shall be so installed that their proper functioning will not be hindered by the nature of the vessel's contents.

(i) Discharge lines from pressure relief devices shall be designed to facilitate drainage or shall be fitted with drains to prevent liquid from lodging in the discharge side of the pressure relief device, and such lines shall lead to a safe place of discharge. The size of the discharge lines shall be such that any pressure that may exist or develop will not reduce the relieving capacity of the pressure relief devices below that required to properly protect the vessel, or adversely affect the proper operation of the pressure relief devices [see Nonmandatory Appendix M and Section XIII, 3.2.2(a)].

(j) For rupture disks that are marked with only a lot number in accordance with Section XIII, 4.7.2, following the installation of the disk, the metal tag shall be sealed to the installation in a manner that will prevent removal of the disk without breaking the seal. The seal shall identify the organization responsible for performing the installation.

SUBSECTION B REQUIREMENTS PERTAINING TO METHODS OF FABRICATION OF PRESSURE VESSELS

PART UW REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY WELDING

GENERAL

(25) UW-1 SCOPE

The rules in Part UW are applicable to pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements in Subsections C and D.

(25) UW-2 SERVICE RESTRICTIONS

(a) When vessels are to contain lethal[42] substances, either liquid or gaseous, all butt-welded joints shall be fully radiographed in accordance with UW-51, except for butt welds subject to the provisions of (2) and (3) below and UW-11(a)(4), and butt welds in stiffening rings designed under the rules of UG-29. ERW pipe or tube is not permitted to be used as a shell or nozzle in lethal service applications. When fabricated of carbon or low alloy steel, such vessels shall be postweld heat treated in accordance with Tables UCS-56-1 through UCS-56-11, unless otherwise exempted by Table UCS-56-1, General Note (b)(3). When a vessel is to contain fluids of such a nature that a very small amount mixed or unmixed with air is dangerous to life when inhaled, it shall be the responsibility of the user and/or the user's designated agent to determine if it is lethal. If determined as lethal, the user and/or the user's designated agent [see U-2(a)] shall so advise the designer and/or Manufacturer. It shall be the responsibility of the Manufacturer to comply with the applicable Code provisions (see UCI-2 and UCD-2).

(1) The joints of various categories (see UW-3) shall be as follows:

(-a) Except for welded tubes and pipes internal to heat exchanger shells, all joints of Category A shall be Type No. (1) of Table UW-12.

(-b) All Category B and C joints shall be Type No. (1) or No. (2) of Table UW-12.

(-c) Category C joints for lap joint stub ends shall be as follows:

(-1) The finished stub end shall be attached to its adjacent shell with a Type No. (1) or Type No. (2) joint of Table UW-12. The finished stub end can be made from a forging or can be machined from plate material. [See UW-13(h).]

(-2) The lap joint stub end shall be fabricated as follows:

(+a) The weld is made in two steps as shown in Figure UW-13.5.

(+b) Before making weld No. 2, weld No. 1 is examined by full radiography in accordance with UW-51, regardless of size. The weld and fusion between the weld buildup and neck is examined by ultrasonics in accordance with Mandatory Appendix 12.

(+c) Weld No. 2 is examined by full radiography in accordance with UW-51.

(-3) The finished stub end may either conform to ASME B16.9 dimensional requirements or be made to a non-standard size, provided all requirements of this Division are met.

(-d) All joints of Category D shall be full penetration welds extending through the entire thickness of the vessel wall or nozzle wall.

(2) Radiographic examination of the welded seam in exchanger tubes and pipes, to a material specification permitted by this Division, which are butt welded without the addition of filler metal may be waived, provided the tube or pipe is totally enclosed within a shell of a vessel which meets the requirements of (a).

(3) If only one side of a heat exchanger contains a lethal substance, the other side need not be built to the rules for a vessel in lethal service if:

(-a) exchanger tubes are seamless; or

(-b) exchanger tubes conform to a tube specification permitted by this Division, are butt welded without addition of filler metal, and receive in lieu of full radiography all of the following nondestructive testing and examination:

(-1) hydrotest in accordance with the applicable specification;

(-2) pneumatic test under water in accordance with the applicable material specification, or if not specified, in accordance with SA-688;

(-3) ultrasonic or nondestructive electric examination of sufficient sensitivity to detect surface calibration notches in any direction in accordance with SA-450, Section 25.

No improvement in longitudinal joint efficiency is permitted because of the additional nondestructive tests.

(4) All elements of a combination vessel in contact with a lethal substance shall be constructed to the rules for lethal service.

(b) When vessels are to operate below certain temperatures designated by Part UCS (see UCS-68), or impact tests of the material or weld metal are required by Part UHA, the joints of various categories (see UW-3) shall be as follows:

(1) All joints of Category A shall be Type No. (1) of Table UW-12 except that for austenitic chromium–nickel stainless steel Types 304, 304L, 316, 316L, 321, and 347, which satisfy the requirements of UHA-51(d), Type No. (2) joints may be used.

(2) All joints of Category B shall be Type No. (1) or No. (2) of Table UW-12.

(3) All joints of Category C shall be full penetration welds extending through the entire section at the joint.

(4) All joints of Category D shall be full penetration welds extending through the entire thickness of the vessel wall or nozzle wall except that partial penetration welds may be used between materials listed in Table UHA-23 as follows:

(-a) for materials shown in UHA-51(g)(3)(-a)(-1) and UHA-51(g)(3)(-b)(-1) at minimum design metal temperatures (MDMTs) of −320°F (−196°C) and warmer;

(-b) for materials shown in UHA-51(g)(3)(-a)(-2) and UHA-51(g)(3)(-b)(-2) at MDMTs of −50°F (−45°C) and warmer.

(c) Unfired steam boilers with design pressures exceeding 50 psi (343 kPa)shall satisfy all of the following requirements:

(1) All joints of Category A (see UW-3) shall be in accordance with Type No. (1) of Table UW-12, and all joints in Category B shall be in accordance with Type No. (1) or No. (2) of Table UW-12.

(2) All butt-welded joints shall be fully radiographed except under the provisions of UW-11(a)(4) and except for ERW pipe weld seams. When using ERW pipe as the shell of an unfired steam boiler, its thickness shall not exceed ½ in. (13 mm), its diameter shall not exceed 24 in. (DN 600), and the ERW weld shall be completed using high frequency (HFI) welding.

(3) When fabricated of carbon or low-alloy steel, such vessels shall be postweld heat treated.

(4) See also U-1(g)(1), UG-16.2, UG-16.3, and UG-150(d).

(d) Pressure vessels or parts subject to direct firing [see U-1(h)] may be constructed in accordance with all applicable rules of this Division and shall meet the following requirements:

(1) All welded joints in Category A (see UW-3) shall be in accordance with Type No. (1) of Table UW-12, and all welded joints in Category B, when the thickness exceeds $^5/_8$ in. (16 mm), shall be in accordance with Type No. (1) or No. (2) of Table UW-12. No welded joints of Type No. (3) of Table UW-12 are permitted for either Category A or B joints in any thickness.

(2) When the thickness at welded joints exceeds $^5/_8$ in. (16 mm) for carbon (P-No. 1) steels and for all thicknesses for low alloy steels (other than P-No. 1 steels), postweld heat treatment is required. For all other material and in any thickness, the requirements for postweld heat treatment shall be in conformance with the applicable Subsections of this Division. See also U-1(h), UG-16.2, UG-16.3, and UCS-56.

(3) The user, the user's designated agent, or the Manufacturer of the vessel shall make available to the Inspector the calculations used to determine the design temperature of the vessel. The provisions of UG-20 shall apply except that pressure parts in vessel areas having joints other than Type Nos. (1) and (2) of Table UW-12, subject to direct radiation and/or the products of combustion, shall be designed for temperatures not less than the maximum surface metal temperatures expected under operating conditions.

UW-3 WELDED JOINT CATEGORY (25)

The term "Category" as used herein defines the location of a joint in a vessel, but not the type of joint. The "Categories" established by this paragraph are for use elsewhere in this Division in specifying special requirements regarding joint type and degree of inspection for certain welded pressure joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements will apply to joints of a given category only when specifically so stated. The joints included in each category are designated as Categories A, B, C, D, and F below. Figure UW-3 illustrates typical joint locations included in each category. Welded joints not defined by the category designations include but are not limited to Part UEJ, Figure UEJ-3-1, sketches (a), (c), and (d) corner joints; Section VIII, Division 2, Table 4.11.1 jacket-closure-to-shell welds; diffusion welds in diffusion-welded plate packs; and Part UEB,

Figure UEB-13 fillet welds. Unless limited elsewhere in this Division, the UW-9(a) permissible weld joint types may be used with welded joints that are not assigned a category.

(a) Category A. Longitudinal and spiral welded joints within the main shell, communicating chambers,[43] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[44] of a flat-sided vessel; any butt-welded joint within a flat tubesheet; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

(b) Category B. Circumferential welded joints within the main shell, communicating chambers, nozzles, or transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers. Circumferential welded joints are butt joints if the half-apex angle, α, is equal to or less than 30 deg and angle joints when α is greater than 30 deg. (See Figure UW-3.)

(c) Category C. Welded joints connecting flanges, lap joint stub ends, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers any welded joint connecting one side plate to another side plate of a flat-sided vessel.

(d) Category D. Welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads, to diffusion-welded plate packs, or to flat-sided vessels, and those joints connecting nozzles to communicating chambers (for nozzles at the small end of a transition in diameter, see Category B).

(e) Category F. Welded joints connecting tubes to tubesheets per UW-20.

MATERIALS

UW-5 GENERAL

(a) Pressure Parts. Materials used in the construction of welded pressure vessels shall comply with the requirements for materials given in UG-4 through UG-15, and shall be proven of weldable quality. Satisfactory qualification of the welding procedure under Section IX is considered as proof.

(b) Nonpressure Parts. Materials used for nonpressure parts that are welded to the pressure vessel shall be proven of weldable quality as described below.

(1) For material identified in accordance with UG-10, UG-11, UG-15, or UG-93, satisfactory qualification of the welding procedure under Section IX is considered as proof of weldable quality.

(2) For materials not identifiable in accordance with UG-10, UG-11, UG-15, or UG-93, but identifiable as to nominal chemical analysis and mechanical properties, P-Number under Section IX, Table QW/QB-422, or to a material specification not permitted in this Division, satisfactory qualification of the welding procedure under Section IX is considered as proof of weldable quality. For materials identified by P-Numbers, the provisions of Section IX, Table QW/QB-422 may be followed for welding procedure qualification. The welding procedure need only be qualified once for a given nominal chemical analysis and mechanical properties or material specification not permitted in this Division.

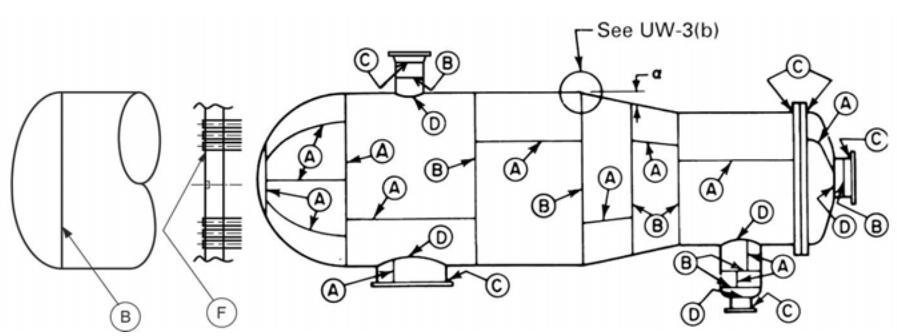
(3) Materials that cannot be identified are to be considered as unassigned material and qualified per the requirements of Section IX.

(c) Two materials of different specifications may be joined by welding provided the requirements of Section IX are met.

(d) Materials joined by the electroslag and electrogas welding processes shall be limited to ferritic steels and the following austenitic steels which are welded to produce a ferrite containing weld metal: SA-240 Types 304, 304L, 316, and 316L; SA-182 F304, F304L, F316, and F316L; SA-351 CF3, CF3A, CF3M, CF8, CF8A, and CF8M.

(25)

Figure UW-3
Illustration of Welded Joint Locations Typical of Categories A, B, C, D, and F



(e) Welding of SA-841 by the electroslag or electrogas welding process is prohibited.

(f) Materials joined by the inertia and continuous drive friction welding processes shall be limited to materials assigned P-Numbers in Section IX and shall not include rimmed or semikilled steel.

(25) **UW-6 NONMANDATORY GUIDELINES FOR WELDING MATERIAL SELECTIONS**

The Manufacturer is responsible for the selection of welding consumables and welding processes. These nonmandatory guidelines for welding material selections are intended to achieve suitable vessel performance for the intended service conditions, but may not be appropriate for every condition in the absence of specific technical reasons to do otherwise. The user or the user's designated agent should inform the Manufacturer when a specific filler metal selection is necessary to achieve satisfactory vessel performance for the intended service conditions.

(a) The tensile strength of the weld should equal or exceed that of the base metals to be joined. When base metals of different strengths are to be joined by welding, the tensile strength of the weld metal should equal or exceed that of the weaker of the two base metals.

(b) When considerations such as corrosion resistance, toughness, or fatigue resistance require selecting welding consumables or processes that produce weld joints of a lesser strength than either of the base metals, the strength of the resulting joint should be reviewed and the design adjusted as appropriate for the intended service conditions.

(c) When welding materials of like composition, the nominal composition of the weld metal should be analogous to the nominal composition of the base metal, except when creep or corrosion performance is an overriding consideration.

(d) When welding materials of different nominal composition, the nominal composition of the weld metal should be analogous to one of the base metals, or be of an acceptable alternative composition.

(e) When joining nonferrous base metals, filler metal selections should follow the recommendations of the manufacturer of the nonferrous metal or applicable industry associations.

DESIGN

(25) **UW-8 GENERAL**

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsections C and D.

UW-9 DESIGN OF WELDED JOINTS

(a) Permissible Types. The types of welded joints permitted for Category A, B, C, and D joints are listed in Table UW-12, together with the limiting plate thickness permitted for each type. Other types of welded joints are specifically allowed in this Subsection. Only butt-type joints may be used with the permitted welding processes in UW-27 that include the application of pressure.

(b) Welding Grooves. The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration. Qualification of the welding procedure, as required in UW-28, is acceptable as proof that the welding groove is satisfactory.

(c) Tapered Transitions

(1) A tapered transition having a length not less than *three* times the offset between the adjacent surfaces of abutting sections, as shown in Figure UW-9-1, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section, or by more than $^{1}/_{8}$ in. (3 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. When the transition is formed by removing material from the thicker section, the minimum thickness of that section, after the material is removed, shall not be less than that required by UG-23(c). When the transition is formed by adding additional weld metal beyond what would otherwise be the edge of the weld, such additional weld metal buildup shall be subject to the requirements of UW-42. The butt weld may be partly or entirely in the tapered section or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential, butt welded joints connecting formed heads to main shells are contained in UW-13.

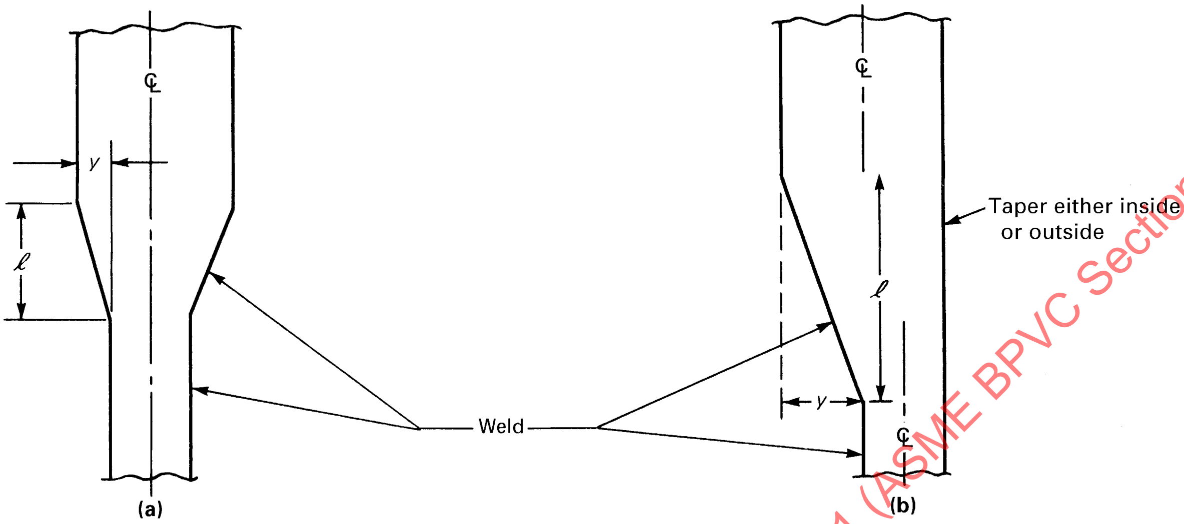
(2) The centerline of a butt weld attaching a component (flange, pipe, etc.) to a thickened neck nozzle that has a taper transition angle, α, less than 71.5 deg shall be located a minimum of $1.5t_n$ from the taper (see Figure UW-9-2), where t_n is the nominal thickness of the nozzle wall at the butt weld.

(d) Except when the longitudinal joints are radiographed 4 in. (100 mm) each side of each circumferential welded intersection, vessels made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered or separated by a distance of at least five times the thickness of the thicker plate.

(e) Lap Joints. For lapped joints, the surface overlap shall be not less than four times the thickness of the inner plate except as otherwise provided for heads in UW-13.

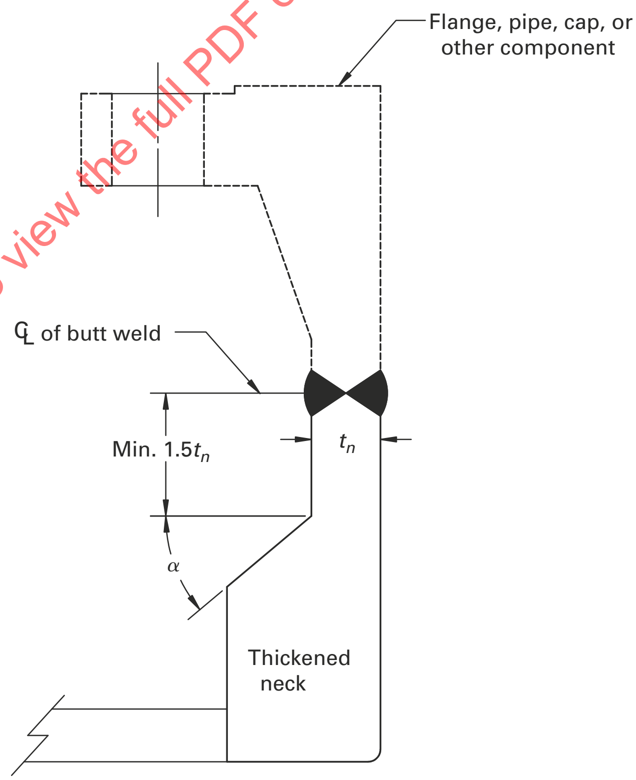
(f) Welded Joints Subject to Bending Stresses. Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. Corner joints, with fillet welds only,

Figure UW-9-1
Butt Welding of Plates of Unequal Thickness



GENERAL NOTES:
(a) $\ell \geq 3y$, where ℓ is the required length of taper and y is the offset between the adjacent surfaces of abutting sections.
(b) Length of required taper, ℓ, may include the width of the weld.
(c) In all cases, ℓ shall be not less than $3y$.

Figure UW-9-2
Butt Welding of Components to Thickened Neck Nozzles



shall not be used unless the plates forming the corner are properly supported independently of such welds. (See UW-18.)

(g) Minimum Weld Sizes. Sizing of fillet and partial penetration welds shall take into consideration the loading conditions in UG-22 but shall not be less than the minimum sizes specified elsewhere in this Division.

(h) Offset Joints. Shell courses may be joined to one another or to a dished head by butt welds having one plate offset as shown in Figure UW-9-3. The weld bead may be deposited on the inside of the vessel only when the weld is accessible for inspection after the vessel is completed. The offset shall be smooth and symmetrical and shall not be machined or otherwise reduced in thickness through the conical portion of the offset. The thickness of the shaded area may be less than the required thickness of the offset component when acting solely as a backing strip for the weld joint. There shall be a uniform force fit with the mating section at the root of the weld.

(1) Definitions

t = nominal thickness of offset shell or head in Figure UW-9-3.

t_1 = nominal thickness of shell or head attached to offset in Figure UW-9-3.

(2) Should the offset contain a longitudinal joint, the following shall apply:

(-a) The longitudinal weld within the area of the offset shall be ground substantially flush with the parent metal prior to the offsetting operation.

(-b) The longitudinal weld from the edge of the plate through the offset shall be examined by either the magnetic particle or liquid penetrant method after the offsetting operation. Cracks and crack-like defects are unacceptable and shall be repaired or removed.

(3) For joints connecting hemispherical heads to shells, the following shall apply:

(-a) t or t_1 = $^3/_8$ in. (10 mm) maximum.

(-b) Maximum difference in thickness between t or t_1 = $^3/_{32}$ in. (2.5 mm).

(-c) Use of Figure UW-9-3 for joints connecting hemispherical heads to shells shall be noted in the "Remarks" section of the Manufacturer's Data Report.

(4) For joints connecting other dished heads to shells, the distance between the shell edge that is not offset and the tangent of the head knuckle shall be not less than $3t$.

(25) UW-10 POSTWELD HEAT TREATMENT

Pressure vessels and pressure vessel parts shall be postweld heat treated as prescribed in UW-40 when postweld heat treatment is required in the applicable Part of Subsection C or Subsection D.

UW-11 RADIOGRAPHIC AND ULTRASONIC EXAMINATION

(a) Full Radiography. The following welded joints shall be examined radiographically for their full length in the manner prescribed in UW-51:

(1) all butt welds in the shell and heads of vessels used to contain lethal substances [see UW-2(a)];

(2) all butt welds in the shell and heads of vessels in which the nominal thickness [see (g) below] at the welded joint exceeds $1^1/_2$ in. (38 mm), or exceeds the lesser thicknesses prescribed in UCS-57, UNF-57, UHA-33, UCL-35, or UCL-36 for the materials covered therein, or as otherwise prescribed in UHT-57, ULW-51, ULW-52(d), ULW-54, or ULT-57;

(3) all butt welds in the shell and heads of unfired steam boilers having design pressures

(-a) exceeding 50 psi (350 kPa) [see UW-2(c)];

(-b) not exceeding 50 psi (350 kPa) [see UW-2(c)] but with nominal thickness at the welded joint exceeding the thickness specified in (2) above;

(4) all butt welds in nozzles, communicating chambers, etc., with the nominal thickness at the welded joint that exceeds the thickness in (2) above or attached to the shell or heads of vessels under (1)or (3) above that are required to be fully radiographed; however, except as required by UHT-57(a), Category B and C butt welds in nozzles and communicating chambers that neither exceed NPS 10 (DN 250) nor $1^1/_8$ in. (29 mm) wall thickness do not require any radiographic examination;

(5) all Category A and D butt welds in the shell and heads of vessels where the design of the joint or part is based on a joint efficiency permitted by UW-12(a), in which case:

(-a) Category A and B welds connecting the shell or heads of vessels shall be of Type No. (1) or Type No. (2) of Table UW-12;

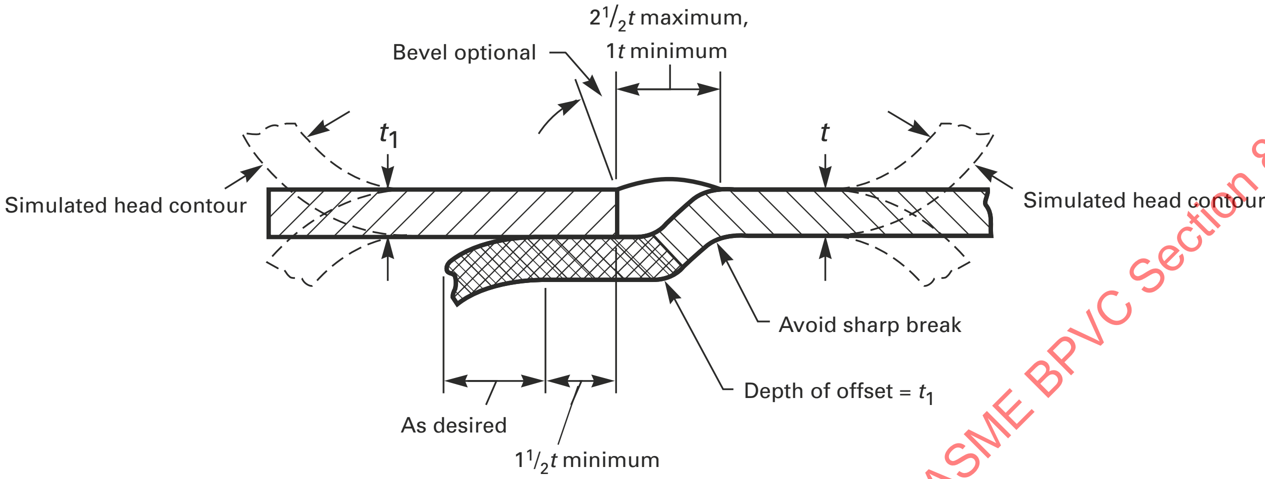
(-b) Category B or C butt welds [but not including those in nozzles and communicating chambers except as required in (4) above] which intersect the Category A butt welds in the shell or heads of vessels or connect seamless vessel shell or heads shall, as a minimum, meet the requirements for spot radiography in accordance with UW-52. Spot radiographs required by this paragraph shall not be used to satisfy the spot radiography rules as applied to any other weld increment.

(6) all butt welds joined by electrogas welding with any single pass greater than $1^1/_2$ in. (38 mm) and all butt welds joined by electroslag welding;

(7) all Category A welds in a tubesheet shall be of Type (1) of Table UW-12;

(8) exemptions from radiographic examination for certain welds in nozzles and communicating chambers as described in (2), (4), and (5) above take precedence over the radiographic requirements of Subsection C.

Figure UW-9-3
Butt Welding With One Plate Edge Offset



(b) Spot Radiography. Except when spot radiography is required for Category B or C butt welds by (a)(5)(-b) above, butt-welded joints made in accordance with Type No. (1) or (2) of Table UW-12 which are not required to be fully radiographed by (a) above, may be examined by spot radiography. Spot radiography shall be in accordance with UW-52. If spot radiography is specified for the entire vessel, radiographic examination is not required of Category B and C butt welds in nozzles and communicating chambers that exceed neither NPS 10 (DN 250) nor $1^1/_8$ in. (29 mm) wall thickness.

NOTE: This requirement specifies spot radiography for butt welds of Type No. (1) or No. (2) that are used in a vessel, but does not preclude the use of fillet and/or corner welds permitted by other paragraphs, such as for nozzle and manhole attachments, welded stays, flat heads, etc., which need not be spot radiographed.

(c) No Radiography. Except as required in (a) above, no radiographic examination of welded joints is required when the vessel or vessel part is designed for external pressure only, or when the joint design complies with UW-12(c).

(d) Electrogas welds in ferritic materials with any single pass greater than $1^1/_2$ in. (38 mm) and electroslag welds in ferritic materials shall be ultrasonically examined throughout their entire length in accordance with the requirements of Mandatory Appendix 12. This ultrasonic examination shall be done following the grain refining (austenitizing) heat treatment or postweld heat treatment.

(e) In addition to the requirements in (a) and (b) above, all welds made by the electron beam or laser beam process shall be ultrasonically examined for their entire length in accordance with the requirements of Mandatory Appendix 12. Ultrasonic examination may be waived if the following conditions are met:

(1) The nominal thickness at the welded joint does not exceed $^1/_4$ in. (6 mm).

(2) For ferromagnetic materials, the welds are either examined by the magnetic particle examination technique in accordance with Mandatory Appendix 6 or examined by the liquid penetrant examination technique in accordance with Mandatory Appendix 8.

(3) For nonferromagnetic materials, the welds are examined by the liquid penetrant examination technique in accordance with Mandatory Appendix 8.

(f) When radiography is required for a welded joint in accordance with (a) and (b) above, and the weld is made by the inertia and continuous drive friction welding processes, the welded joints shall also be ultrasonically examined for their entire length in accordance with Mandatory Appendix 12.

(g) For radiographic and ultrasonic examination of butt welds, the definition of nominal thickness at the welded joint under consideration shall be the nominal thickness of the thinner of the two parts joined. Nominal thickness is defined in Mandatory Appendix 3, 3-2.

UW-12 JOINT EFFICIENCIES (25)

Table UW-12 gives the joint efficiencies, E, to be used in the equations of this Division for welded joints. Except as required by UW-11(a)(5), a joint efficiency depends only on the type of joint and on the extent of examination of the joint and does not depend on the extent of examination of any other joint. The user or the user's designated agent [see U-2(a)] shall establish the type of joint and the extent of examination when the rules of this Division do not mandate specific requirements. Rules for determining the applicability of the efficiencies are found in the various paragraphs covering design equations [for example, see UG-24 and UG-27]. For further guidance, see Nonmandatory Appendix L.

(a) A value of E not greater than that given in column (a) of Table UW-12 shall be used in the design calculations for fully radiographed butt joints [see UW-11(a)], except that when the requirements of UW-11(a)(5) are not met, a value of E not greater than that given in column (b) of Table UW-12 shall be used.

(b) A value of E not greater than that given in column (b) of Table UW-12 shall be used in the design calculations for spot radiographed butt-welded joints [see UW-11(b)].

(c) A value of E not greater than that given in column (c) of Table UW-12 shall be used in the design calculations for welded joints that are neither fully radiographed nor spot radiographed [see UW-11(c)].

(d) Seamless vessel sections or heads shall be considered equivalent to welded parts of the same geometry in which all Category A welds are Type No. 1. For calculations involving circumferential stress in seamless vessel sections or for thickness of seamless heads, E = 1.0 when the spot radiography requirements of UW-11(a)(5)(-b) are met. E = 0.85 when the spot radiography requirements of UW-11(a)(5)(-b) are not met, or when the Category A or B welds connecting seamless vessel sections or heads are Type No. 3, 4, 5, 6, or 8 of Table UW-12.

(e) Welded pipe or tubing shall be treated in the same manner as seamless, but with allowable tensile stress taken from the welded product values of the stress tables, and the requirements of (d) applied.

(f) A value of E not greater than 0.80 may be used in the equations of this Division for joints completed by any of the permitted welding processes in UW-27 that include the application of pressure, except for electric resistance welding, provided the welding process used is permitted by the rules in the applicable Parts of Subsection C for the material being welded. The quality of such welds used in vessels or parts of vessels shall be proved as follows: Test specimens shall be representative of the production welding on each vessel. They may be removed from the shell itself or from a prolongation of the shell including the longitudinal joint, or, in the case of vessels not containing a longitudinal joint, from a test plate of the same material and thickness as the vessel and welded in accordance with the same procedure. One reduced-section tension test and two side-bend tests shall be made in accordance with, and shall meet the requirements of Section IX, QW-150 and QW-160.

(25) UW-13 ATTACHMENT DETAILS

(a) Definitions

K = min(K_y, K_t)
K_t = min($S_{t,a}/S_{t,1}$)
K_y = min($S_{y,a}/S_{y,1}$)
S_t = specified minimum tensile strength at room temperature, ksi (MPa)
$S_{t,a}$ = actual tensile strength from through-thickness (Z direction) tension test specimen at room temperature, ksi (MPa)
S_y = specified minimum yield strength at room temperature, ksi (MPa)
$S_{y,a}$ = actual yield strength from through-thickness (Z direction) tension test specimen at room temperature, ksi (MPa)
t_h = nominal thickness of head
t_p = minimum distance from outside surface of flat head to edge of weld preparation measured as shown in Figure UW-13.2
t_s = nominal thickness of shell

(See UG-27, UG-28, UG-32, UG-34, and other paragraphs for additional definitions.)

(b) See below.

(1) Ellipsoidal, torispherical, and other types of formed heads shall be attached to the shell with a butt weld, or as illustrated in the applicable Figure UW-13.1, sketches (a), (b), (c), and (d). The construction shown in sketch (e) may also be used for end heads when the thickness of the shell section of the vessel does not exceed $^5/_8$ in. (16 mm) [see also (c) below]. Limitations relative to the use of these attachments shall be as given in the sketches and related notes and in Table UW-12. Figure UW-13.1, sketches (f), (g), and (h) are examples of attachment methods which are not permissible.

(2) Formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Figure UW-13.1, using the applicable sketch. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(3) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Figure UW-13.1, sketches (i) and (j) shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $^1/_8$ in. (3 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt-welded attachment [see Figure UW-13.1, sketches (k) and (l)], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line. When the transition is formed by removing material from the thicker section, the minimum thickness of that section, after the material is removed, shall not be less than that required by UG-23(c). When the transition is formed by adding additional weld metal beyond what would otherwise be the edge of the weld, such additional weld metal buildup shall be subject to the requirements of UW-42. The centerline misalignment between shell and head shall be no greater than one-half the difference between the actual shell and head thickness, as illustrated in Figure UW-13.1, sketches (i), (j), (k), and (l).

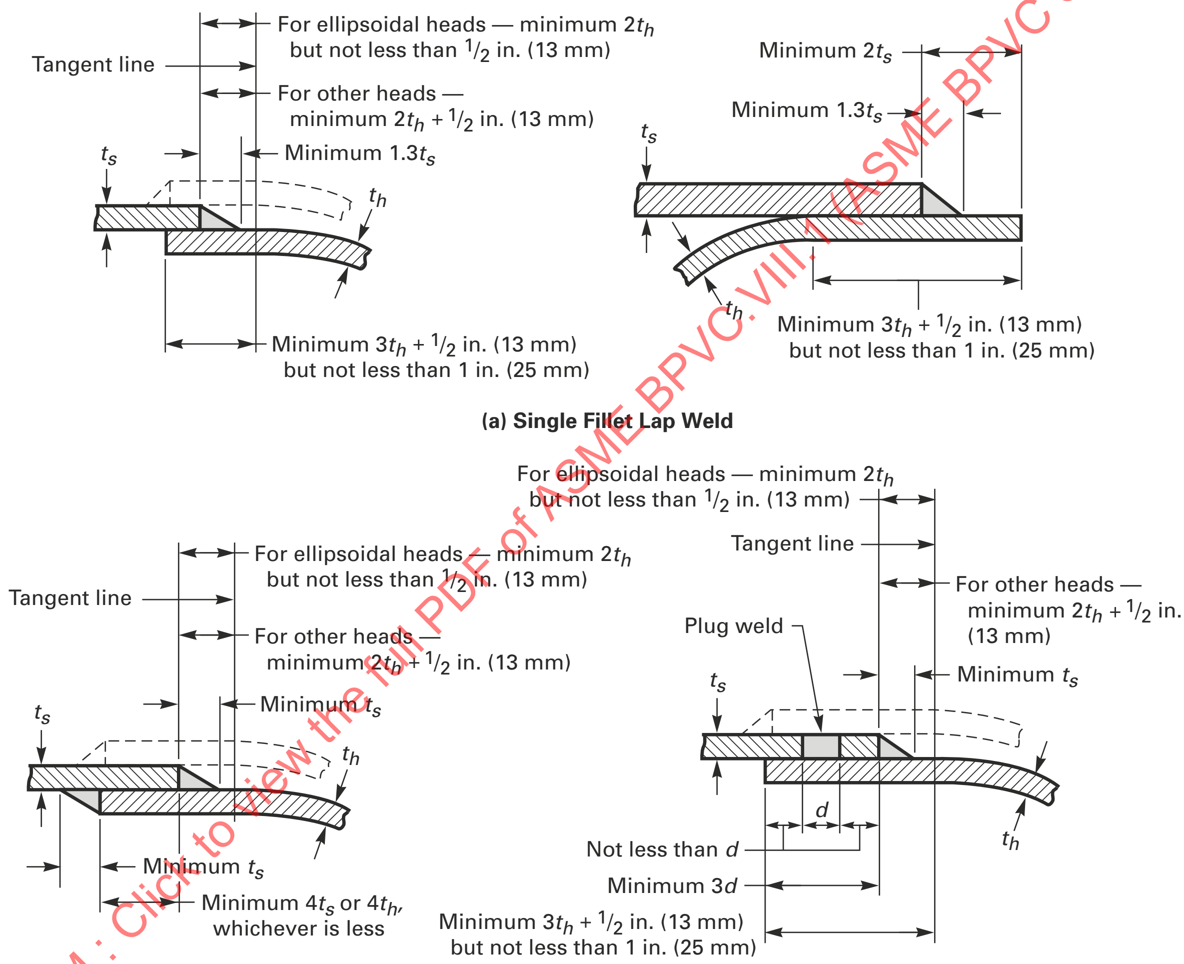
Table UW-12
Maximum Allowable Joint Efficiencies for Welded Joints

Type No.	Joint Description	Limitations	Joint Category	Extent of Radiographic or Ultrasonic Examination [Note (1)], [Note (2)], [Note (3)] (a) Full [Note (4)]	(b) Spot [Note (5)]	(c) None
(1)	Butt joints welded from both sides, or from one side only without a permanent backing strip, that are verified as having achieved full penetration and fusion as required by UW-35.	None	A, B, C, and D	1.00	0.85	0.70
(2)	Butt joints welded from one side only with a permanent backing strip that achieves full penetration and fusion as required by UW-35.	For circumferential butt joints with one plate offset, the nominal thickness shall not exceed $^5/_8$ in. (16 mm). See UW-9(h) and Figure UW-9-3.	A, B, C, and D	0.90	0.80	0.65
(3)	Butt joints welded from one side only without a permanent backing strip that cannot be verified as having achieved full penetration and fusion as required by UW-35.	Circumferential butt joints only, not over $^5/_8$ in. (16 mm) thick and not over 24 in. (600 mm) outside diameter	A, B, and C	NA	NA	0.60
(4)	Double full fillet lap joint that meets the requirements of UW-35.	*(a)* Longitudinal joints not over $^3/_8$ in. (10 mm) thick *(b)* Circumferential joints not over $^5/_8$ in. (16 mm) thick	A B and C [Note (6)]	NA NA	NA NA	0.55 0.55
(5)	Single full fillet lap joints with plug welds conforming to UW-17 that meets the requirements of UW-35..	*(a)* Circumferential joints [Note (7)] for attachment of heads not over 24 in. (600 mm) outside diameter to shells not over $^1/_2$ in. (13 mm) thick *(b)* Circumferential joints for the attachment to shells of jackets not over $^5/_8$ in. (16 mm) in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than $1^1/_2$ times the diameter of the hole for the plug.	B C	NA NA	NA NA	0.50 0.50
(6)	Single full fillet lap joints without plug welds that meets the requirements of UW-35.	*(a)* For the attachment of heads convex to pressure to shells not over $^5/_8$ in. (16 mm) required thickness, only with use of fillet weld on inside of shell; or *(b)* for attachment of heads having pressure on either side, to shells not over 24 in. (600 mm) inside diameter and not over $^1/_4$ in. (6 mm) required thickness with fillet weld on outside of head flange only	A and B A and B	NA NA	NA NA	0.45 0.45
(7)	Corner joints, full penetration, partial penetration, and/or fillet welded	As limited by Figures UW-13.2 and UW-16.1	C and D [Note (8)]	NA	NA	NA
(8)	Angle joints	Design per U-2(g) for Category B and C joints	B, C, and D	NA	NA	NA
(9)	Tube-to-tubesheet joints	As limited by Figures UW-20.1 and UW-20.2	F	NA	NA	NA

GENERAL NOTE: E = 1.00 for butt joints in compression.

NOTES:
(1) Some welding processes require ultrasonic examination in addition to radiographic examination, and other processes require ultrasonic examination in lieu of radiographic examination. See UW-11 for some additional requirements and limitations that may apply.
(2) Joint efficiency assignment rules of UW-12(d) and UW-12(e) shall be considered and may further reduce the joint efficiencies to be used in the required thickness calculations.
(3) The rules of UW-12(f) may be used in lieu of the rules of this Table at the Manufacturer's option.
(4) See UW-12(a) and UW-51.
(5) See UW-12(b) and UW-52.
(6) For Type No. 4 Category C joint, limitation not applicable for bolted flange connections.
(7) Joints attaching hemispherical heads to shells are excluded.
(8) There is no joint efficiency E in the design equations of this Division for Category C and D corner joints. When needed, a value of E not greater than 1.00 may be used.

Figure UW-13.1
Heads Attached to Shells

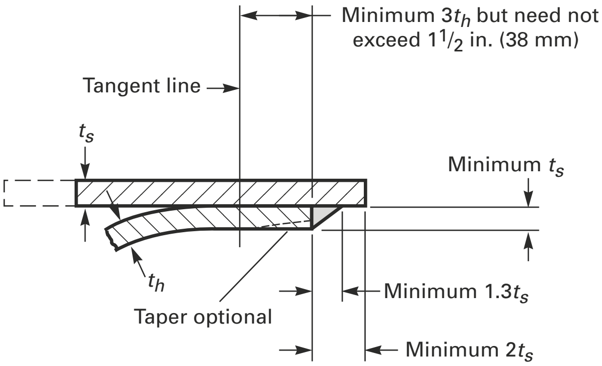


(a) Single Fillet Lap Weld

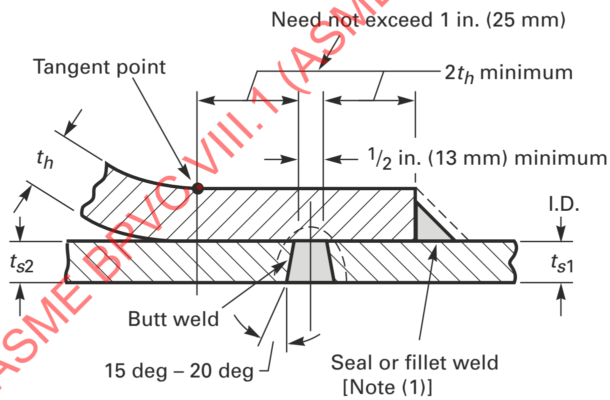
(b) Double Fillet Lap Weld

(c) Single Fillet Lap Weld With Plug Welds

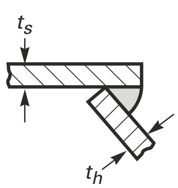
Figure UW-13.1 Heads Attached to Shells (Cont'd)



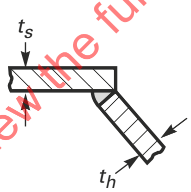
(d) Single Fillet Lap Weld



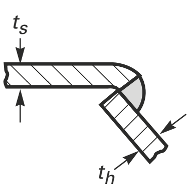
(e) Intermediate Head [See Notes (2) and (3)]



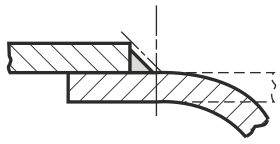
(f-1) Not Permissible



(f-2) Not Permissible

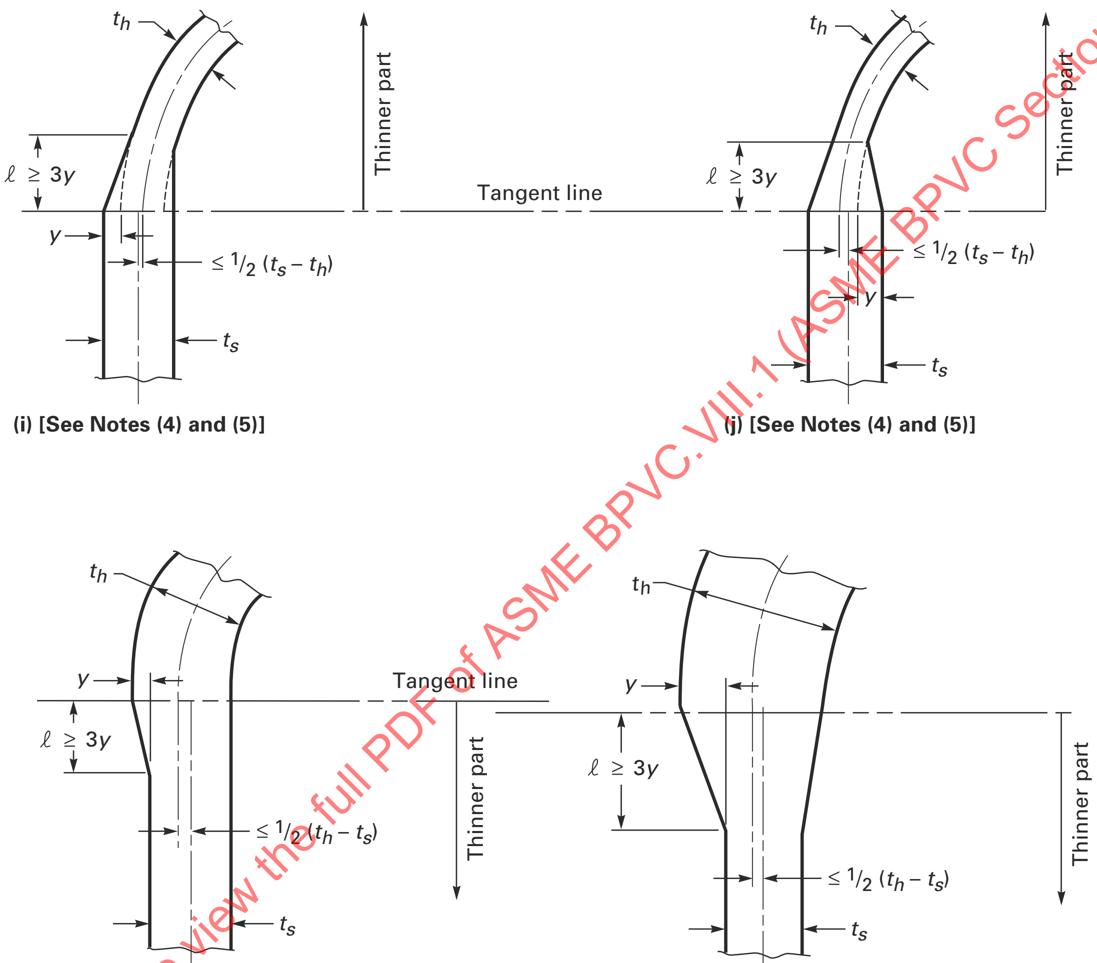


(g) Not Permissible



(h) Not Permissible

Figure UW-13.1
Heads Attached to Shells (Cont'd)

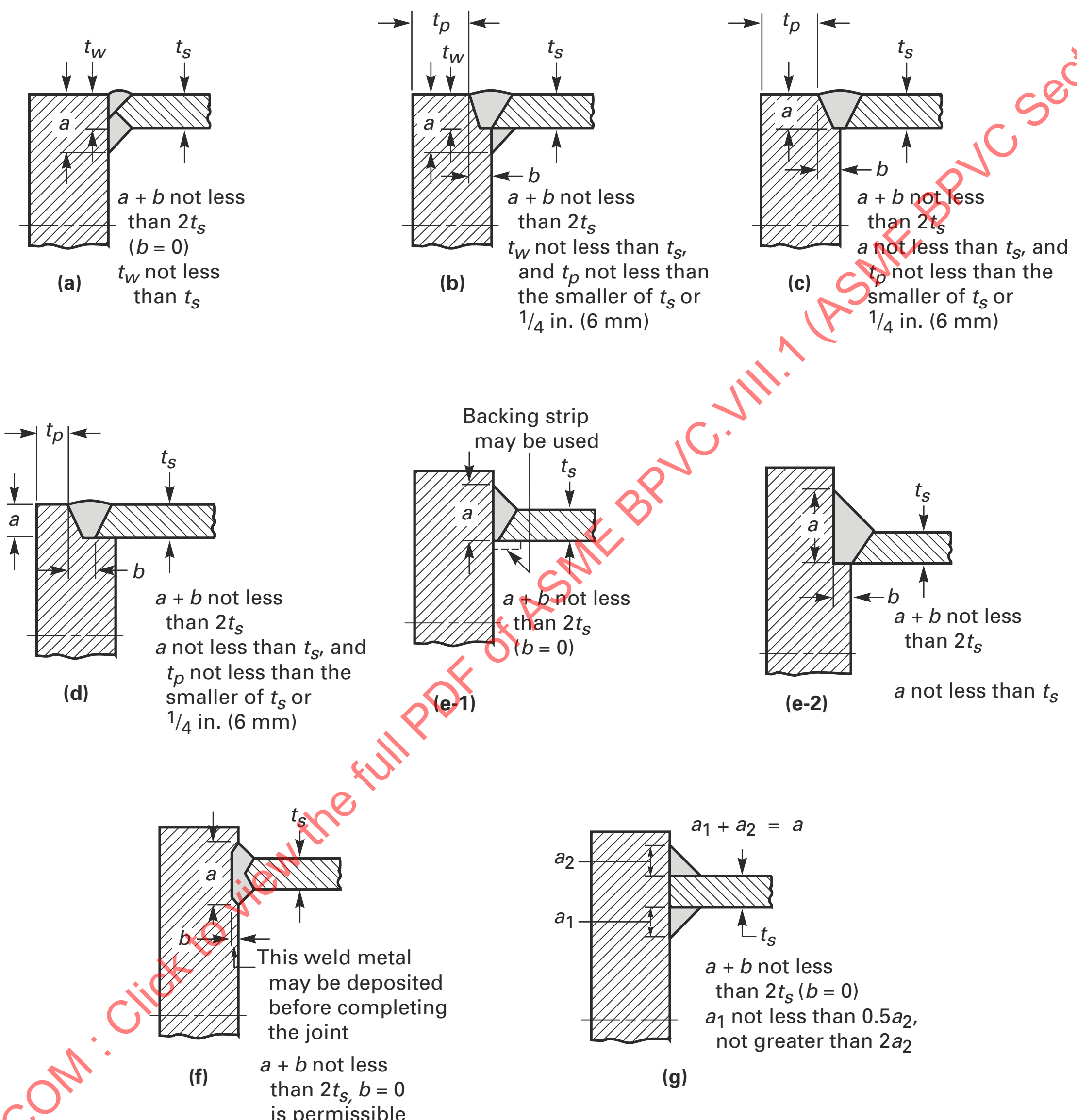


GENERAL NOTE: See Table UW-12 for limitations.

NOTES:
(1) See UW-13(c)(2).
(2) Butt weld and fillet weld, if used, shall be designed to take shear at $1\frac{1}{2}$ times the differential pressure than can exist.
(3) t_{s1} and t_{s2} may be different.
(4) In all cases, the projected length of taper, ℓ, shall be not less than $3y$.
(5) Length of required taper, ℓ, may include the width of the weld. The shell plate centerline may be on either side of the head plate centerline.
(6) In all cases, ℓ shall be not less than $3y$ when t_h exceeds t_s. Minimum length of skirt is $3t_h$ but need not exceed $1\frac{1}{2}$ in. (38 mm) except when necessary to provide required length of taper. When t_h is equal to or less than $1.25t_s$, length of skirt shall be sufficient for any required taper.

(25)

Figure UW-13.2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint



Typical Unstayed Flat Heads, Tubesheets Without a Bolting Flange, and Side Plates of Rectangular Vessels [See Note (1)]

Figure UW-13.2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint (Cont'd)

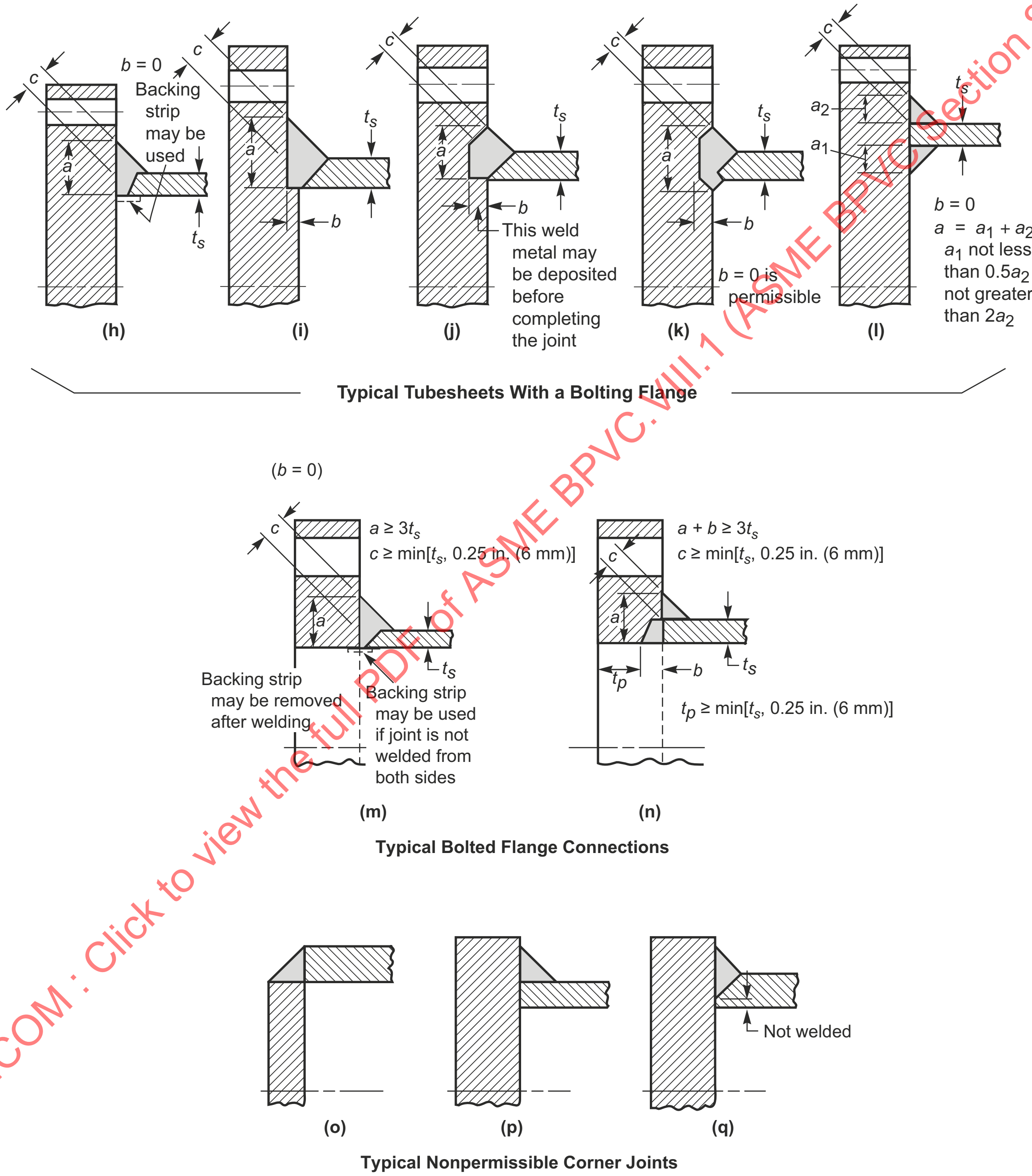
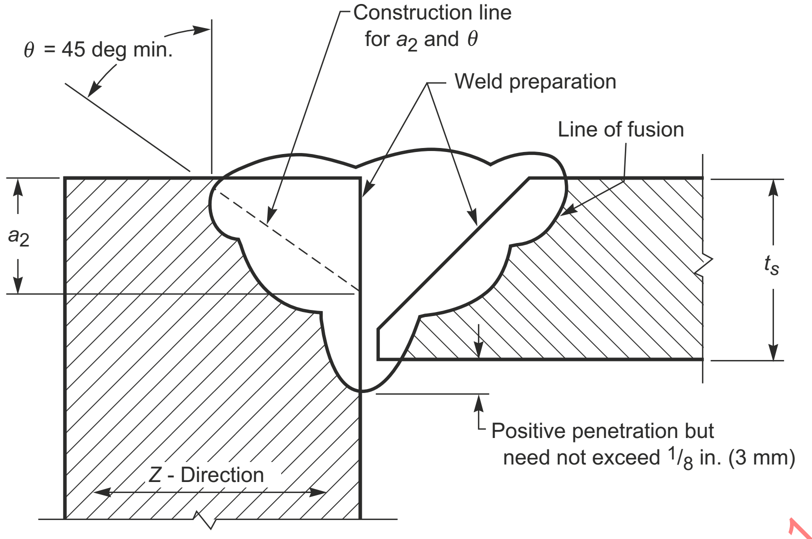
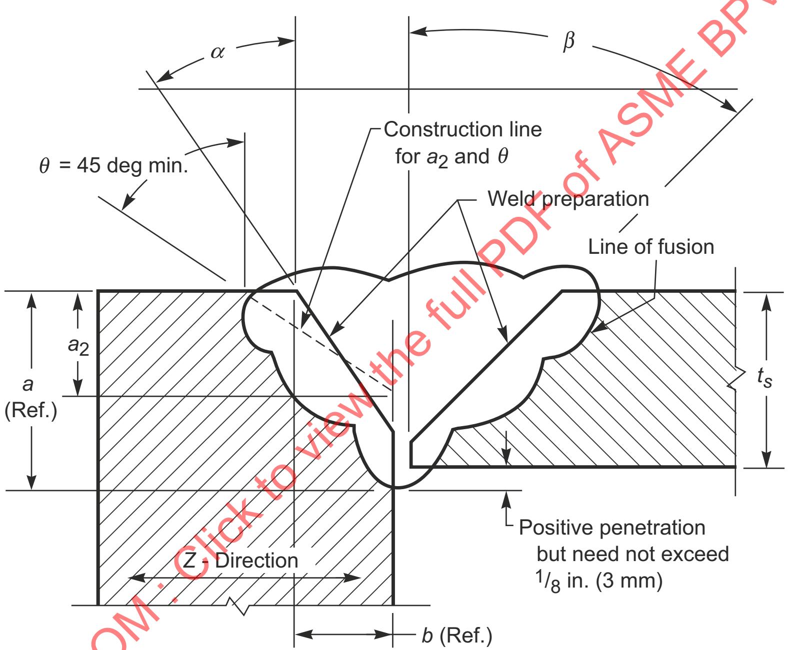


Figure UW-13.2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint (Cont'd)



K	a_2/t_s Not Less Than
0.6	0.29
0.7	0.23
0.8	0.17
0.9	0.09
1.0	0

(r) Details for One Member Beveled [See Note (2)]



K	Min. a_2/t_s for α Not Less Than 15 deg	Min. a_2/t_s for α Not Less Than 30 deg	Min. a_2/t_s for α Not Less Than 45 deg
0.6	0.85	0.55	0.29
0.7	0.81	0.47	0.23
0.8	0.74	0.38	0.17
0.9	0.58	0.23	0.09
1.0	0	0	0

See sketch (r) above for table with values of K and a_2/t_s

(s) Details for Both Members Beveled [See Note (2)]

GENERAL NOTES:

(a) $a + b$ not less than $2t_s$; c not less than $0.7t_s$ or $1.4t_r$, whichever is less. This note does not apply to sketches (r) and (s)..

(b) t_s and t_r are as defined in UG-34(b).

(c) Dimension b is produced by the weld preparation and shall be verified after fit up and before welding.

NOTES:

(1) For unstayed flat heads, see also UG-34.

(2) Interpolation of α and K is permitted.

(4) Non-butt-welded bolting flanges shall be attached to formed heads as illustrated in Mandatory Appendix 1, Figure 1-6.

(c) See below.

(1) Intermediate heads, without limit to thickness, of the type shown in Figure UW-13.1, sketch (e) may be used for all types of vessels provided that the outside diameter of the head skirt is a close fit inside the overlapping ends of the adjacent length of cylinder.

(2) The butt weld and fillet weld shall be designed to take shear based on $1^1/_2$ times the maximum differential pressure that can exist. The allowable stress value for the butt weld shall be 70% of the stress value for the vessel material and that of the fillet 55%. The area of the butt weld in shear is the width at the root of the weld times the length of weld. The area of the fillet weld is the minimum leg dimension times the length of weld. The fillet weld may be omitted if the construction precludes access to make the weld, and the vessel is in noncorrosive service.

(d) The requirements for the attachment of welded unstayed flat heads to shells are given in UG-34 and in (e) and (f) hereunder.

(e) When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Figure UW-13.2, the joint shall meet the following requirements [see also UG-93.4]:

(1) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b, respectively (see Figure UW-13.2).

(2) For flange rings of bolted flanged connections, as shown in Figure UW-13.2, sketches (m) and (n), the sum of a and b shall be not less than three times the nominal wall thickness of the abutting pressure part.

(3) For other components, the sum a and b shall be not less than two times the nominal wall thickness of the abutting pressure part unless the provisions of (f) are satisfied. Examples of such components are flat heads, tubesheets with or without a projection having holes for a bolted connection, and the side plates of a rectangular vessel.

(4) Other dimensions at the joint shall be in accordance with details as shown in Figure UW-13.2.

(5) Joint details that have a dimension through the joint less than the thickness of the shell, head or other pressure part, or that provide attachment eccentric thereto, are not permissible. See Figure UW-13.2, sketches (o), (p), and (q).

(f) When a multipass corner weld joint is constructed in accordance with Figure UW-13.2, sketch (r) or sketch (s), all rules in the Code pertaining to welded joints shall apply except that the requirement "$a + b$ not less than $2t_s$" of (e)(3) shall be replaced with the following requirements:

(1) A sample corner weld joint shall be prepared to qualify the weld procedure, and a sample corner weld joint shall be prepared to qualify each welder or welding operator. The Manufacturer shall prepare the sample corner weld joint with nominal thickness and configuration matching that to be employed with the following tolerances:

(-a) The sample thinner plate shall match the thickness of the production thinner plate within $\pm^1/_4$ in. (±6 mm).

(-b) The sample thicker plate shall be at least 1.5 times the thickness of the sample thinner plate.

The sample shall be sectioned, polished, and etched to clearly delineate the line of fusion. Acceptability shall be determined by measurements of the line of fusion for use in the calculations for compliance with Figure UW-13.2, sketch (r) or sketch (s). The sample shall be free from slag, cracks, and lack of fusion. A sample corner weld shall be prepared for each P-Number, except that a sample prepared to qualify a joint made from material with a given value for K [see (4)] may be used to qualify a joint made from material having an equal or higher value for K but not vice versa.

(2) This sample corner weld joint is an addition to the Welding Procedure Specification Qualification and the Welder and Welding Operator Performance Qualification requirements of Section IX. The following essential variables apply for both the procedure and performance qualification, in addition to those of Section IX:

(-a) a change in the nominal size of the electrode or electrodes used and listed in the PQR;

(-b) a change in the qualified root gap exceeding $\pm^1/_{16}$ in. (±1.5 mm);

(-c) addition or deletion of nonmetallic retainers or nonfusing metal retainers;

(-d) a change in the SFA specification filler metal classification or to a weld metal or filler metal composition not covered in the specifications;

(-e) the addition of welding positions other than those qualified;

(-f) for fill passes, a change in amperage exceeding ±25 amp, change in voltage exceeding ±3 V;

(-g) a change in contact tube to work distance exceeding $^1/_4$ in. (6 mm);

(-h) a change from single electrode to multiple electrodes, or vice versa;

(-i) a change in the electrode spacing;

(-j) a change from manual or semiautomatic to machine or automatic welding or vice versa.

(3) After production welding, the back side of the weld shall be subjected to a visual examination to ensure that complete fusion and penetration have been achieved in the root, except where visual examination is locally prevented by an internal member covering the weld.

(4) The following are design, testing, and documentation requirements:

(-a) K shall be taken as 0.6; higher values for K may be used if through-thickness tension testing is performed in accordance with SA-770.

(-b) The tension test results described in (-a) shall be reported on a Material Test Report and shall meet all the mechanical property requirements of the material specification, except for the tensile and yield strengths. The tension test for the tensile and yield strengths may be performed by the material manufacturer, processor, or supplier, or under the control of the Manufacturer. See UG-93(b) and UG-93(c).

(-c) The actual tensile and yield strengths from this tension test shall be reported on the Manufacturer's Data Report.

(5) The maximum value of t_s [see Figure UW-13.2, sketch (r) or sketch (s)] shall be limited to 3 in. (75 mm).

(6) Both members may be beveled as shown in Figure UW-13.2, sketch (s). When the bevel angle, α, is large enough to satisfy the (e)(3) requirements, these alternative rules do not apply. When the bevel angle, α, results in weld fusion dimensions that do not satisfy the (e)(3) requirement that $a + b$ is not less than $2t_s$, the following shall be satisfied:

(-a) The angle α shall be equal to or greater than 15 deg.

(-b) The dimension a_2 shall be measured from the projected surface of the plate being attached as shown in Figure UW-13.2, sketch (s).

(-c) The angle β shall be equal to or greater than 15 deg.

(-d) When a_2/t_s is equal to or exceeds the value corresponding to the K shown in the table in Figure UW-13.2, sketch (s), the requirements in (1) and (2) need not be satisfied. When a_2/t_s is less than this value, all other requirements of (f) shall be satisfied.

(g) When used, the hub of a tubesheet or flat head shall have minimum dimensions in accordance with Figure UW-13.3 and shall meet the following requirements:

(1) When the hub is integrally forged with the tubesheet or flat head, or is machined from a forging, the hub shall meet all the mechanical property requirements of the material specification, measured in the direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as practical.[45]

(2) When the hub is machined from plate, the requirements of Mandatory Appendix 20 shall be met.

(h) When the hub of a lap joint stub end is machined from plate with the hub length in the through thickness direction of the plate, the requirements of Mandatory Appendix 20 shall be met.

(i) In the case of nozzle necks which attach to piping [see U-1(e)(1)(-a)] of a lesser wall thickness, a tapered transition from the weld end of the nozzle may be provided to match the piping thickness although that thickness is less than otherwise required by the rules of this Division. This tapered transition shall meet the limitations as shown in Figure UW-13.4.

UW-14 OPENINGS IN OR ADJACENT TO WELDS (25)

UW-14.1 Opening in a Welded Joint. Any type of opening that meets the requirements for reinforcement given in UG-37 or UG-39 may be located in a welded joint.

UW-14.2 Single Openings in Welded Joints.

UW-14.2.1 Location of Single Openings. Single openings meeting the requirements given in UG-36(c)(3) may be located in head-to-shell or Category B or C butt-welded joints, provided the weld meets the radiographic requirements in UW-51 for a length equal to 3 times the diameter of the opening with the center of the hole at midlength.

UW-14.2.2 Defects in Removed Hole. Defects that are completely removed in cutting the hole shall not be considered in judging the acceptability of the weld.

UW-14.3 Multiple Openings in Welded Joints. In addition to meeting the radiographic requirements of UW-14.2, when multiple openings meeting the requirements given in UG-36(c)(3) are in line in a head-to-shell or Category B or C butt-welded joint, the requirements of UG-53 shall be met or the openings shall be reinforced in accordance with UG-37 through UG-42.

UW-14.4 Edge of Openings in Solid Plate. Except when the adjacent butt weld satisfies the requirement for radiography in UW-14.2, the edge of openings in solid plate meeting the requirements of UG-36(c)(3) shall not be placed closer than $\frac{1}{2}$ in. (13 mm) from the edge of a Category A, B, or C weld for material $1\frac{1}{2}$ in. (38 mm) thick or less.

UW-15 WELDED CONNECTIONS (25)

UW-15.1 Attachment of Nozzles, Other Connections, and Their Reinforcements by Welding. Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as prescribed in UG-41 through shear or tension in the weld, whichever is applicable.

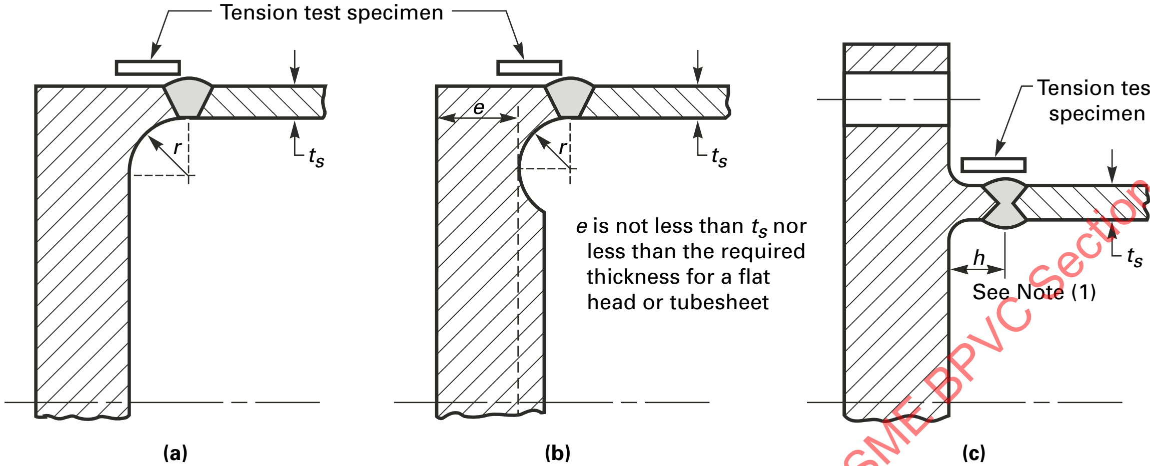
UW-15.2 Weld Areas for Strength Calculations.

UW-15.2.1 The strength of groove welds shall be based on the area subjected to shear or to tension.

UW-15.2.2 The strength of fillet welds shall be based on the area subjected to shear (computed on the minimum leg dimension). The inside diameter of a fillet weld shall be used in figuring its length.

UW-15.3 Exemptions to Weld Strength Calculations. Strength calculations for nozzle attachment welds for pressure loading are not required for the following:

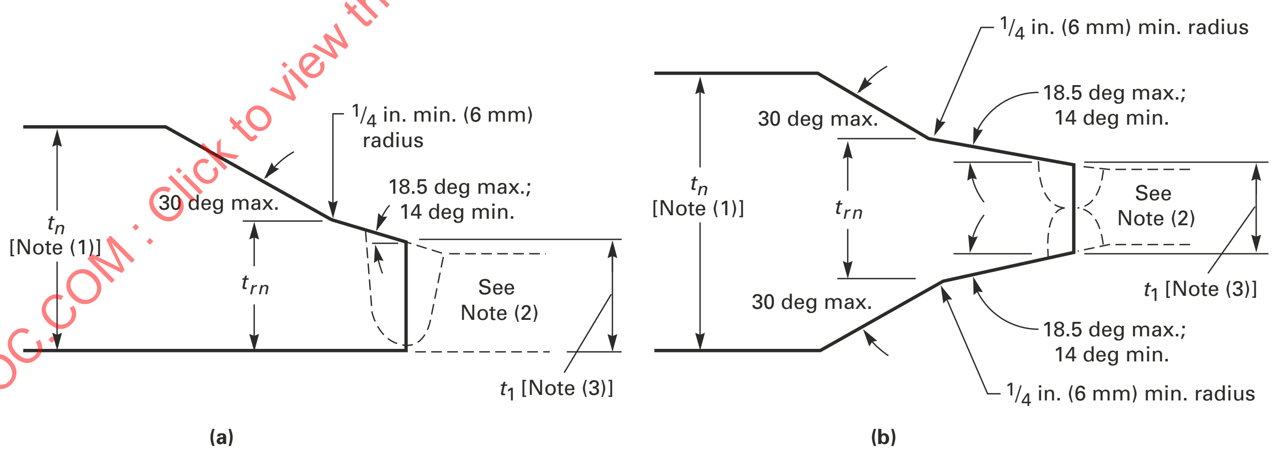
Figure UW-13.3
Typical Pressure Parts With Butt-Welded Hubs



GENERAL NOTES:
(a) Refer to Figure UG-34, sketch (b-2) for dimensional requirements.
(b) Not permissible if machined from rolled plate unless in accordance with Mandatory Appendix 20. See UW-13(g).
(c) Tension test specimen may be located inside or outside the hub.

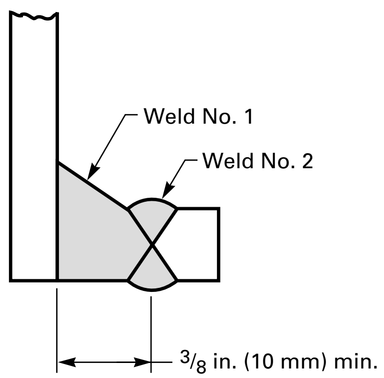
NOTE:
(1) h is the greater of $^3/_4$ in. (19 mm) or $1.5t_s$, but need not exceed 2 in. (50 mm).

Figure UW-13.4
Nozzle Necks Attached to Piping of Lesser Wall Thickness



NOTES:
(1) As defined in UG-40. t_n shall not be less than the thickness required by UG-45.
(2) Weld bevel is shown for illustration only.
(3) t_1 is not less than the greater of
(a) $0.8t_{rn}$, where t_{rn} = required thickness of seamless nozzle wall
(b) minimum wall thickness of connecting pipe

Figure UW-13.5
Fabricated Lap Joint Stub Ends for Lethal Service



(a) Figure UW-16.1, sketches (a), (b), (c), (d), (e), (f-1), (f-2), (f-3), (f-4), (g), (x-1), (y-1), and (z-1) and all the sketches in Figures UHT-18.1 and UHT-18.2

(b) openings that are exempt from the reinforcement requirements by UG-36(c)(3)

(c) openings designed in accordance with the rules for ligaments in UG-53

UW-15.4 Allowable Stress Values for Welds. The allowable stress values used in weld strength calculations for groove and fillet welds in percentages of stress values for the vessel material, which are used with UG-41 calculations, are as follows:

(a) groove-weld tension, 74%

(b) groove-weld shear, 60%

(c) fillet-weld shear, 49%

NOTE: These values are obtained by combining the following factors: $87^1/_2$% for combined end and side loading, 80% for shear strength, and the applicable joint efficiency factors.

UW-16 MINIMUM REQUIREMENTS FOR ATTACHMENT WELDS AT OPENINGS

(a) General

(1) The terms: nozzles, connections, reinforcements, necks, tubes, fittings, pads, and other similar terms used in this paragraph define essentially the same type construction and form a Category D weld joint between the nozzle (or other term) and the shell, head, etc., as defined in UW-3(d).

(2) The location and minimum size of attachment welds for nozzles and other connections shall conform to the requirements of this paragraph in addition to the strength calculations required in UW-15.

(b) Symbols. The symbols used in this paragraph and in Figures UW-16.1 and UW-16.2 are defined as follows:

D_o = outside diameter of neck or tube attached by welding on inside of vessel shell only

G = radial clearance between hole in vessel wall and outside diameter of nozzle neck or tube

r_1 = minimum inside corner radius, the lesser of $^1/_4t$ or $^1/_8$ in. (3 mm)

Radius = $^1/_8$ in. (3 mm) minimum blend radius

t = nominal thickness of vessel shell or head,

t_1 *or* t_2 = not less than the smaller of $^1/_4$ in. (6 mm) or $0.7t_{min}$

t_c = not less than the smaller of $^1/_4$ in. (6 mm) or $0.7t_{min}$ (inside corner welds may be further limited by a lesser length of projection of the nozzle wall beyond the inside face of the vessel wall)

t_e = thickness of reinforcing plate, as defined in UG-40

t_{min} = the smaller of $^3/_4$ in. (19 mm) or the thickness of the thinner of the parts joined by a fillet, single-bevel, or single-J weld

t_n = nominal thickness of nozzle wall

t_w = dimension of attachment welds (fillet, single-bevel, or single-J), measured as shown in Figure UW-16.1

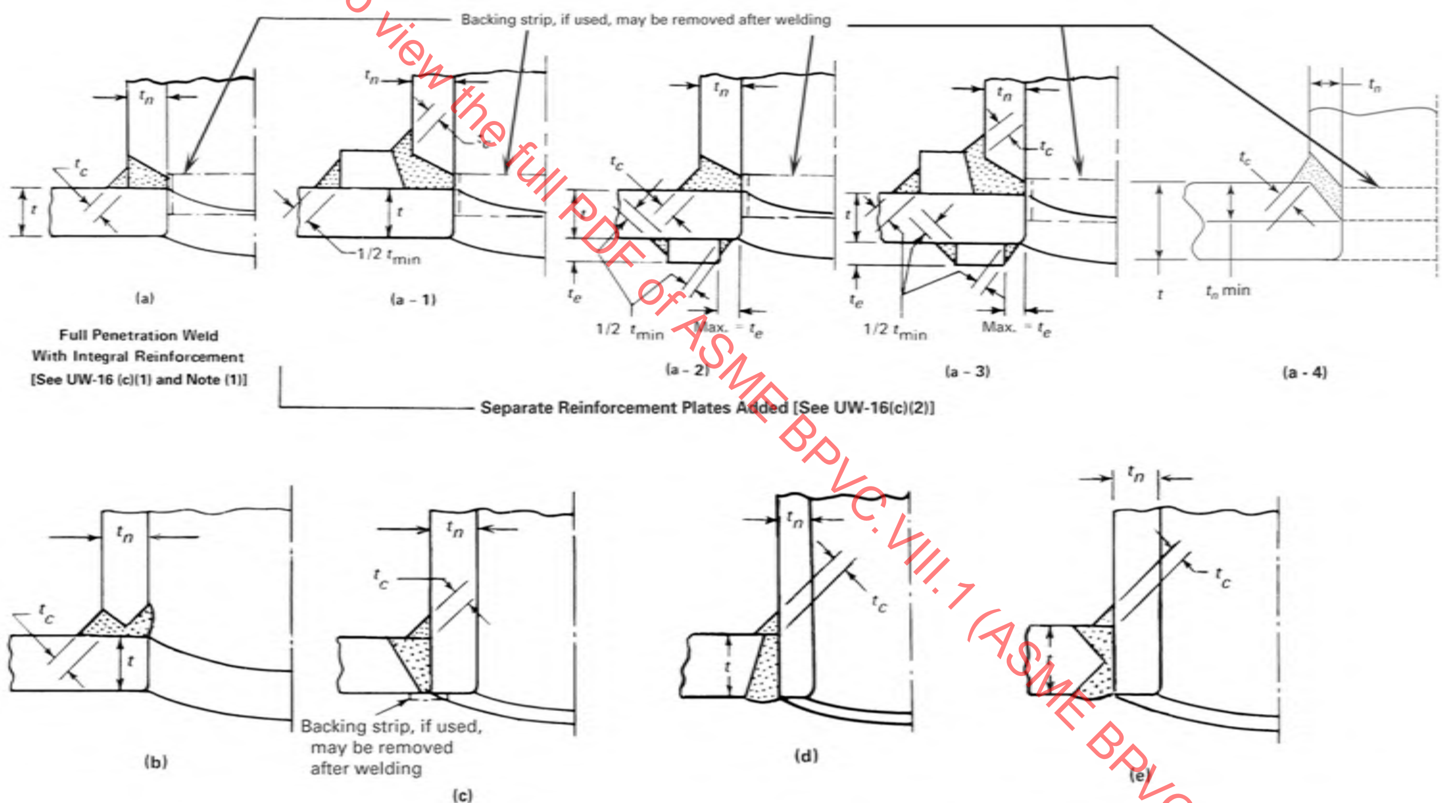
(c) Necks Attached by a Full Penetration Weld. Necks abutting a vessel wall shall be attached by a full penetration groove weld. See Figure UW-16.1, sketches (a) and (b) for examples. Necks inserted through the vessel wall may be attached by a full penetration groove weld. See Figure UW-16.1, sketches (c), (d), and (e). When complete joint penetration cannot be verified by visual inspection or other means permitted in this Division, backing strips or equivalent shall be used with full penetration welds deposited from one side.

If additional reinforcement is required, it shall be provided as integral reinforcement as described in (1) below, or by the addition of separate reinforcement elements (plates) attached by welding as described in (2) below.

(1) Integral reinforcement is that reinforcement provided in the form of extended or thickened necks, thickened shell plates, forging type inserts, or weld buildup which is an integral part of the shell or nozzle wall and, where required, is attached by full penetration welds. See Figure UW-16.1, sketches (a), (b), (c), (d), (e), (f-1), (f-2), (f-3), (f-4), (g), (x-1), (y-1), and (z-1) for examples of nozzles with integral reinforcement where the F factor in Figure UG-37 may be used.

(2) Separate reinforcement elements (plates) may be added to the outside surface of the shell wall, the inside surface of the shell wall, or to both surfaces of the shell wall. When this is done, the nozzle and reinforcement is no longer considered a nozzle with integral reinforcement and the F factor in UG-37(a) shall be F = 1.0. Figure UW-16.1, sketches (a-1), (a-2), and (a-3) depict various applications of reinforcement elements added to sketch (a). Any of these applications of reinforcement elements may be used with necks of the types shown in Figure UW-16.1, sketches (b), (c), (d), and (e) or any other

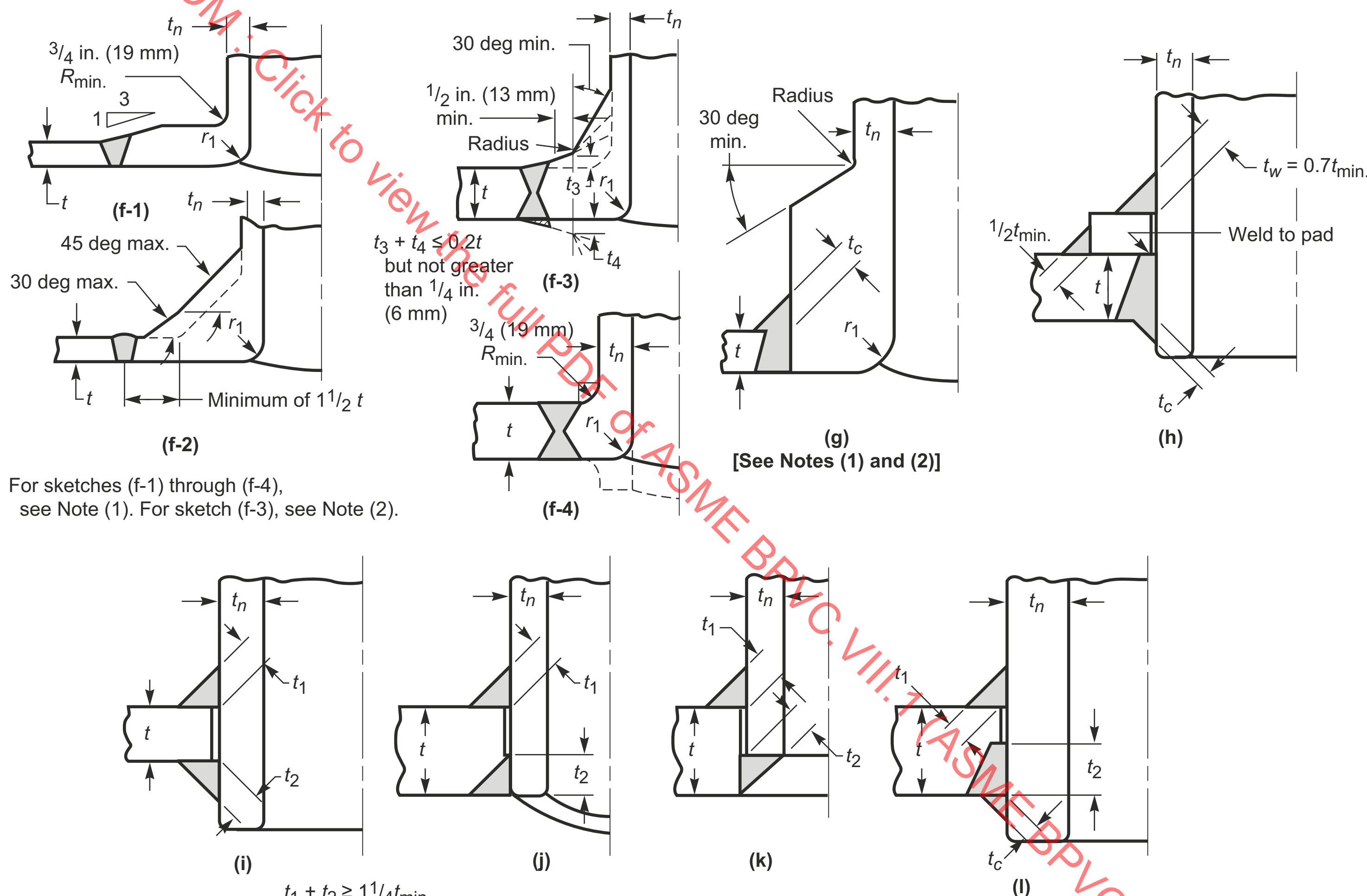
Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc.



Full Penetration Welds to Which Separate Reinforcement Plates May Be Added [See UW-16(c)(2) and Note (1)]

Notes follow on last page of this Figure.

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)

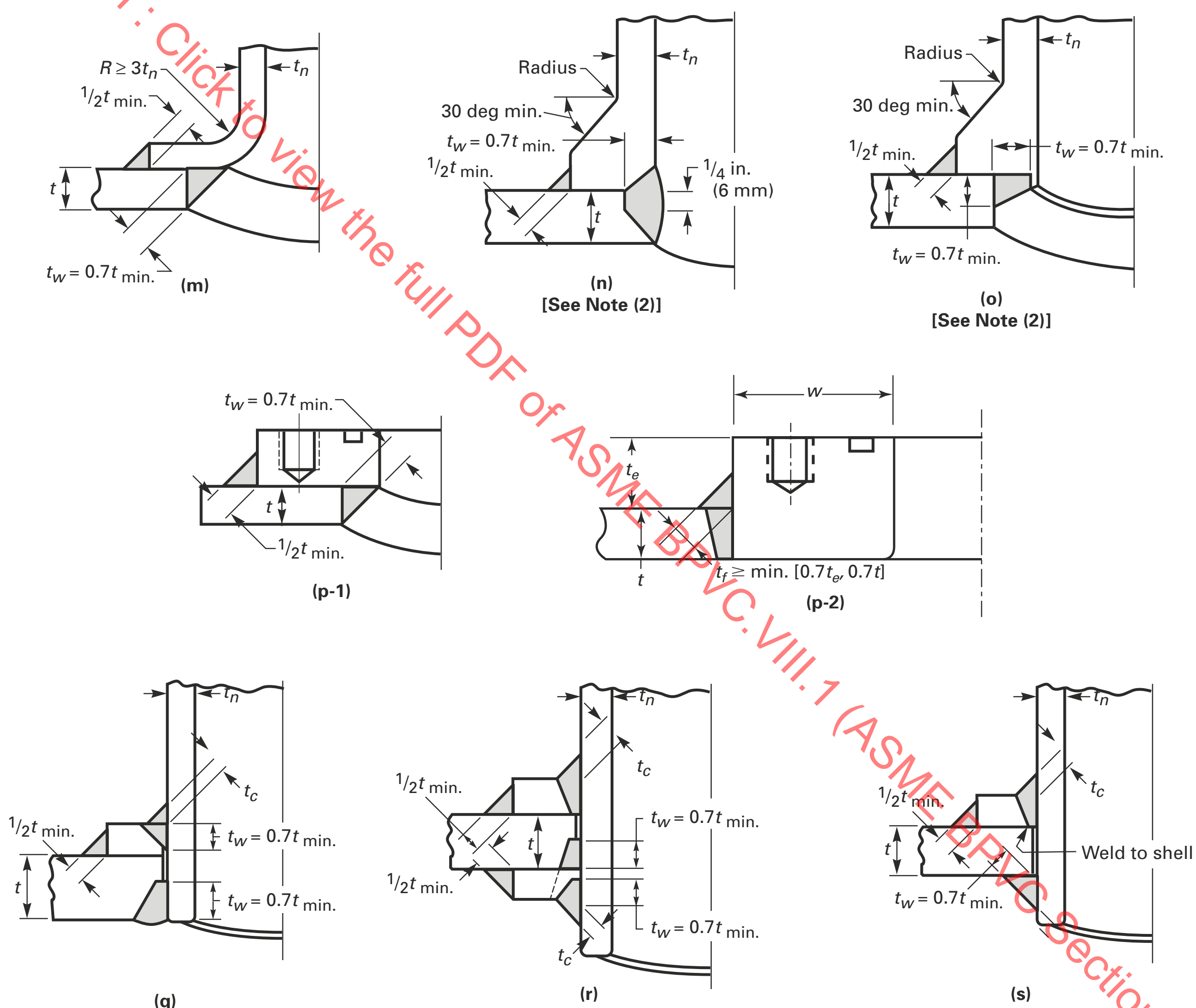


For sketches (f-1) through (f-4), see Note (1). For sketch (f-3), see Note (2).

$t_1 + t_2 \geq 1\frac{1}{4}t_{min.}$
t_1 and t_2 each shall not be less than the smaller of 1/4 in. (6 mm) or $0.7t_{min.}$

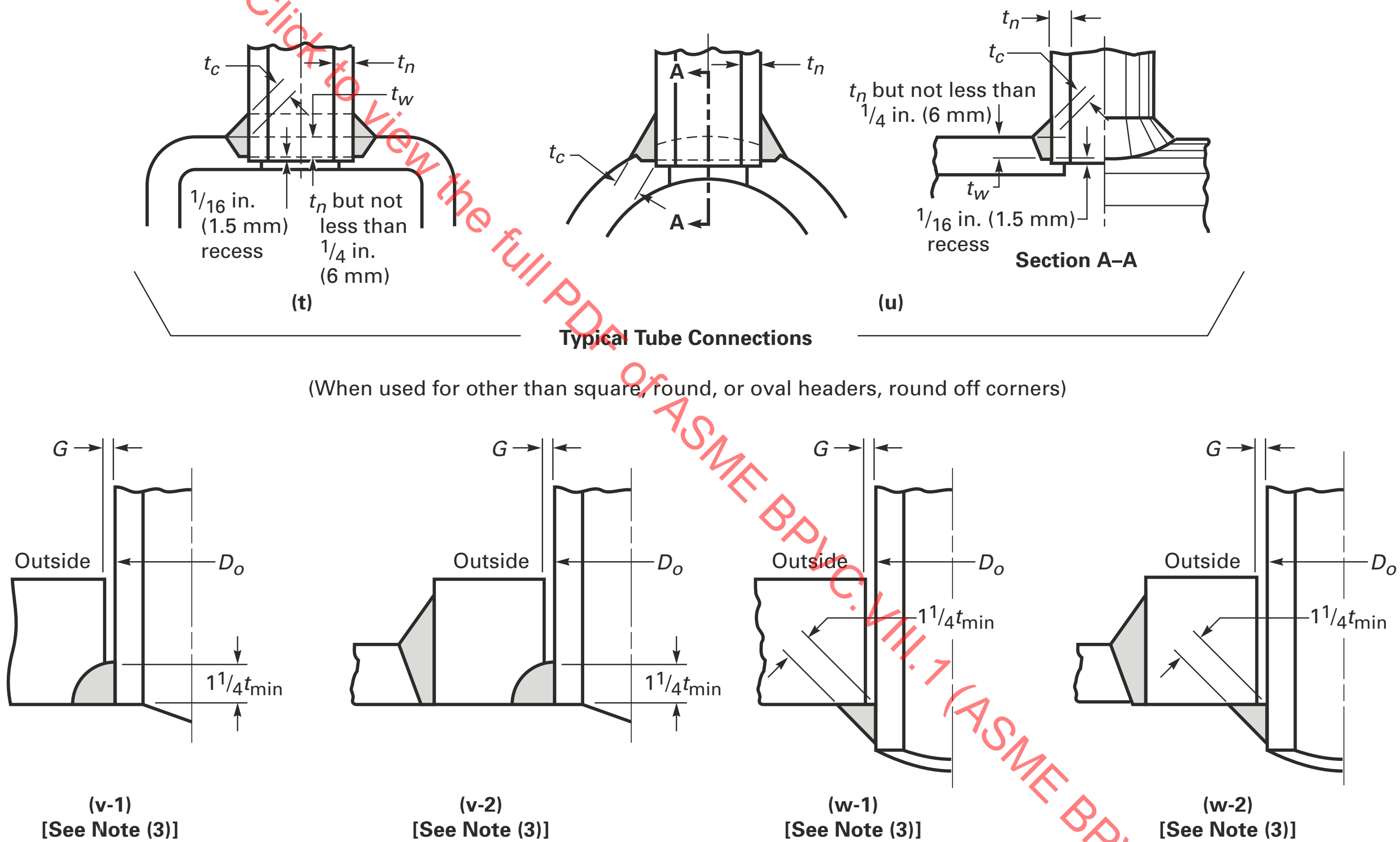
Notes follow on last page of this Figure

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)



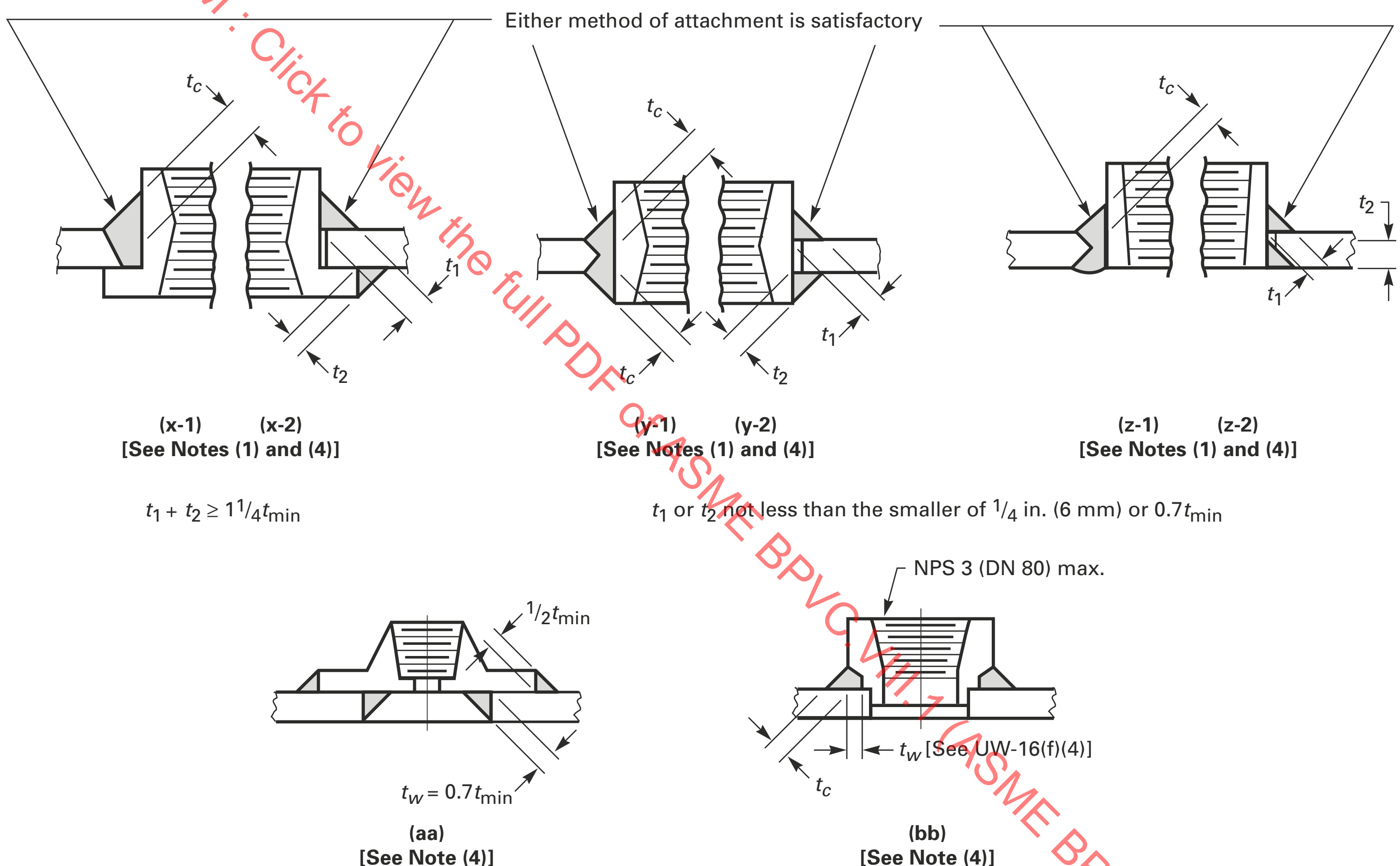
Notes follow on last page of this Figure

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)



Notes follow on last page of this Figure.

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)



NOTES:
(1) Sketches (a), (b), (c), (d), (e), (f-1) through (f-4), (g), (x-1), (y-1), and (z-1) are examples of nozzles with integral reinforcement.
(2) Where the term *Radius* appears, provide a $^1/_8$ in. (3 mm) minimum blend radius.
(3) For sketches (v-1) through (w-2):
(a) For applications where there are no external loads, G = $^1/_8$ in. (3 mm) max.
(b) With external loads
G = 0.005 for $D_o \leq 1$ in. (25 mm); G = 0.010 for 1 in. (25 mm) < $D_o \leq 4$ in. (100 mm); G = 0.015 for 4 in. (100 mm) < $D_o \leq 6^5/_8$ in. (170 mm)
(4) For NPS 3 (DN 80) and smaller, see exemptions in UW-16(f)(2).

integral reinforcement types listed in (1) above. The reinforcement plates shall be attached by welds at the outer edge of the plate, and at the nozzle neck periphery or inner edge of the plate if no nozzle neck is adjacent to the plate.

(-a) The weld at the outer edge of the reinforcement plate shall be a continuous fillet weld with a minimum throat dimension of $\frac{1}{2}t_{min}$.

(-b) The weld at the inner edge of the reinforcement plate which does not abut a nozzle neck shall be a continuous fillet weld with a minimum throat dimension $\frac{1}{2}t_{min}$ [see Figure UW-16.1, sketches (a-2) and (a-3)].

(-c) The weld at the inner edge of the reinforcement plate when the reinforcement plate is full penetration welded to the nozzle neck shall be a continuous fillet weld with a minimum throat dimension of t_c [see Figure UW-16.1, sketches (a-1) and (a-3)].

(-d) The weld at the inner edge of the reinforcement plate when the reinforcement plate is not full penetration welded to the nozzle neck shall be a continuous fillet weld with a minimum throat dimension of $t_w = 0.7t_{min}$ [see Figure UW-16.1, sketch (h)].

(d) Neck Attached by Fillet or Partial Penetration Welds

(1) Necks inserted into or through the vessel wall may be attached by fillet or partial penetration welds, one on each face of the vessel wall. The welds may be any desired combination of fillet, single-bevel, and single-J welds. The dimensions t_1 and t_2 in each weld shall be not less than the smaller of $\frac{1}{4}$ in. (6 mm) or $0.7t_{min}$, and their sum shall be not less than $1\frac{1}{4}t_{min}$. See Figure UW-16.1, sketches (i), (j), (k), and (l).

If additional reinforcement is required, it may be provided in the form of extended or thickened necks, thickened shell plates, forgings, and/or separate reinforcement elements (plates) attached by welding. Weld requirements shall be the same as given in (c)(2) above, except as follows. The welds attaching the neck to the vessel wall or to the reinforcement plate shall consist of one of the following:

(-a) a single-bevel or single-J weld in the shell plate, and a single-bevel or single-J weld in each reinforcement plate. The dimension t_w of each weld shall be not less than $0.7t_{min}$. See Figure UW-16.1, sketches (q) and (r).

(-b) a full penetration groove weld in each reinforcement plate, and a fillet, single-bevel, or single-J weld with a weld dimension t_w not less than $0.7t_{min}$ in the shell plate. See Figure UW-16.1, sketch (s).

(2) Nozzle necks, flared necks, and studding outlet type flanges may be attached by fillet welds or partial penetration welds between the outside diameter or the attachment and the outside surface of the shell and at the inside of the opening in the shell. The throat dimension of the outer attachment weld shall not be less than $\frac{1}{2}t_{min}$. The dimension t_w of the weld at the inside of the shell cutout shall not be less than $0.7t_{min}$. See Figure UW-16.1, sketches (m), (n), (o), and (p-1). Studding-outlet-type flanges may also be attached by full-penetration welds as shown in Figure UW-16.1, sketch (p-2).

(e) Necks and Tubes Up to and Including NPS 6 (DN 150) Attached From One Side Only. Necks and tubes not exceeding NPS 6 (DN 150) may be attached from one side only on either the outside or inside surface of the vessel.

(1) The depth of the welding groove or the throat of the fillet weld shall be at least equal to $1\frac{1}{4}t_{min}$. The radial clearance between the vessel hole and the nozzle outside diameter at the unwelded side shall not exceed the tolerances given in Figure UW-16.1, sketches (v-1), (v-2), (w-1), and (w-2). When welded from the outside only, the neck or tube shall extend to be at least flush to the inside surface of the vessel wall. Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the nozzle neck shall be counted as reinforcement.

(2) As an alternative to (1) above, when the neck or tube is attached from the outside only, a welding groove shall be cut into the surface to a depth of not less than t_n on the longitudinal axis of the opening. It is recommended that a recess $\frac{1}{16}$ in. (1.5 mm) deep be provided at the bottom of the groove, in which to center the nozzle. The dimension t_w of the attachment weld shall be not less than t_n nor less than $\frac{1}{4}$ in. (6 mm). See Figure UW-16.1, sketches (t) and (u).

(f) Standard Fittings: ASME/ANSI or Manufacturer's Standard. The attachment of standard fittings shall meet the following requirements; see (g) for the attachment of bolting pads:

(1) Except as provided in (2) through (6) below, fittings shall be attached by

(-a) two fillet or partial penetration welds, one on each face of the vessel wall; and the minimum weld dimensions shall be as shown in Figure UW-16.1, sketches (x), (y), (z), and (aa); or

(-b) full penetration groove weld [see (c)]

(2) Fittings not exceeding NPS 3 (DN 80) shown on Figure UW-16.1, sketches (x), (y), (z), (aa), and (bb) may be attached by welds that are exempt from size requirements with the following limitations:

(-a) UW-15.1 and UW-15.2 requirements shall be satisfied for UG-22 loadings.

(-b) For partial penetration welds or fillet welds, t_1 or t_2 shall not be less than the smaller of $\frac{3}{32}$ in. (2.5 mm) or $0.7t_{min}$.

(3) See below.

(-a) Fittings not exceeding NPS 3 (DN 80), as shown in Figure UW-16.2, may be attached to vessels that are not subject to rapid fluctuations in pressure by a fillet weld deposited from the outside only without additional reinforcement other than is inherent in the fitting and its attachment to the vessel wall provided all of the following conditions are met

(-1) maximum vessel wall thickness of $\frac{3}{8}$ in. (10 mm);

Table UW-16.1
Minimum Thickness Requirements for Fittings

NPS (DN)	in.	mm
$^1/_8$ (6)	0.11	2.7
$^1/_4$ (8)	0.11	2.7
$^3/_8$ (10)	0.11	2.7
$^1/_2$ (15)	0.14	3.6
$^3/_4$ (20)	0.16	4.2
1 (25)	0.22	5.5
$1^1/_4$ (32)	0.30	7.5
$1^1/_2$ (40)	0.30	7.5
2 (50)	0.31	7.9
$2^1/_2$ (65)	0.37	9.5
3 (80)	0.38	9.5

GENERAL NOTE: For fittings having a specified outside diameter not equal to the outside diameter of an equivalent standard NPS (DN) size, the NPS (DN) size chosen from the table shall be one having an equivalent outside diameter larger than the fitting's outside diameter.

(-2) the maximum size of the opening in the vessel is limited to the outside diameter of the attached pipe plus $^3/_4$ in. (19 mm), but not greater than one-half of the vessel inside diameter;

(-3) the attachment weld throat shall be the greater of the following:

(+a) the minimum nozzle neck thickness required by UG-45 for the same nominal size connection; or

(+b) that necessary to satisfy the requirements of UW-18 for the applicable loadings of UG-22.

(-4) the typical fitting dimension t_f as shown in Figure UW-16.2, sketch (p) shall be sufficient to accommodate a weld leg which will provide a weld throat dimension as required in (-3) above.

(-5) The openings shall meet the requirements provided in UG-36(c)(3)(-c) and UG-36(c)(3)(-d).

(-6) In lieu of the thickness requirements in UG-45, the minimum wall thickness for fittings shall not be less than that shown in Table UW-16.1 plus the thickness added for corrosion allowance.

(-b) If the opening does not meet the requirements of (-a)(-5) or exceeds the requirements of (-a)(-2) above or (5)(-d) below in any direction, or is greater than one-half the vessel inside diameter, the part of the vessel affected shall be subjected to a proof test as required in UG-36(a)(2), or the opening shall be reinforced in accordance with UG-37 and the nozzle or other connection attached, using a suitable detail in Figure UW-16.1, if welded. In satisfying the rules for reinforcement of openings, no material in the nozzle neck shall be counted as reinforcement.

(4) Fittings not exceeding NPS 3 (DN 80) may be attached by a fillet groove weld from the outside only as shown in Figure UW-16.1, sketch (bb). The groove weld t_w shall not be less than the thickness of Schedule 160 pipe (ASME B36.10M) for the nearest equivalent pipe size. [For fittings smaller than NPS $^1/_2$ (DN 15), use Schedule 160 taken from Table 8 of ASME B16.11.]

(5) Flange-type fittings not exceeding NPS 2 (DN 50), with some acceptable types such as those shown in Figure UW-16.2, may be attached without additional reinforcement other than that in the fitting and its attachment to the vessel wall. The construction satisfies the requirements of this Division without further calculation or proof test as permitted in UG-36(c)(3) provided all of the following conditions are met:

(-a) Maximum vessel wall thickness shall not exceed $^3/_8$ in. (10 mm).

(-b) Maximum design pressure shall not exceed 350 psi (2.5 MPa).

(-c) Minimum fillet leg t_f is $^3/_{32}$ in. (2.45 mm).

(-d) The finished opening, defined as the hole in the vessel wall, shall not exceed the outside diameter of the nominal pipe size plus $^3/_4$ in. (19 mm).

(6) Fittings conforming to Figure UW-16.2, sketch (k) not exceeding NPS 3 (DN 80) may be attached by a single fillet weld on the inside of the vessel only, provided the criteria of Figure UW-16.1, sketch (w) and (e)(1) are met.

(g) Bolting Pads: Manufacturer's Standard. The attachment of standard bolting pads shall meet the following requirements:

(1) Except as provided for in (2) and (3), bolting pads shall be attached by a full penetration groove weld or by two fillet or partial penetration welds, one on each face of the vessel wall. The minimum weld dimensions shall be as shown in Figure UW-16.1, sketches (p), (x), (y), (z), and (aa).

(2) Bolting pads as shown in Figure UW-16.3, sketches (a) and (b) may be attached to vessels by a fillet weld deposited from the outside only with the following limitations:

(-a) The maximum vessel wall thickness is $^3/_8$ in. (10 mm), and the bolting pad outside the diameter is not greater than $4^3/_4$ in. (120 mm).

(-b) The maximum size of the opening in the vessel is limited to the following:

(-1) $4^3/_4$ in. (120 mm) for bolting pads that are installed through wall; see Figure UW-16.3, sketch (a)

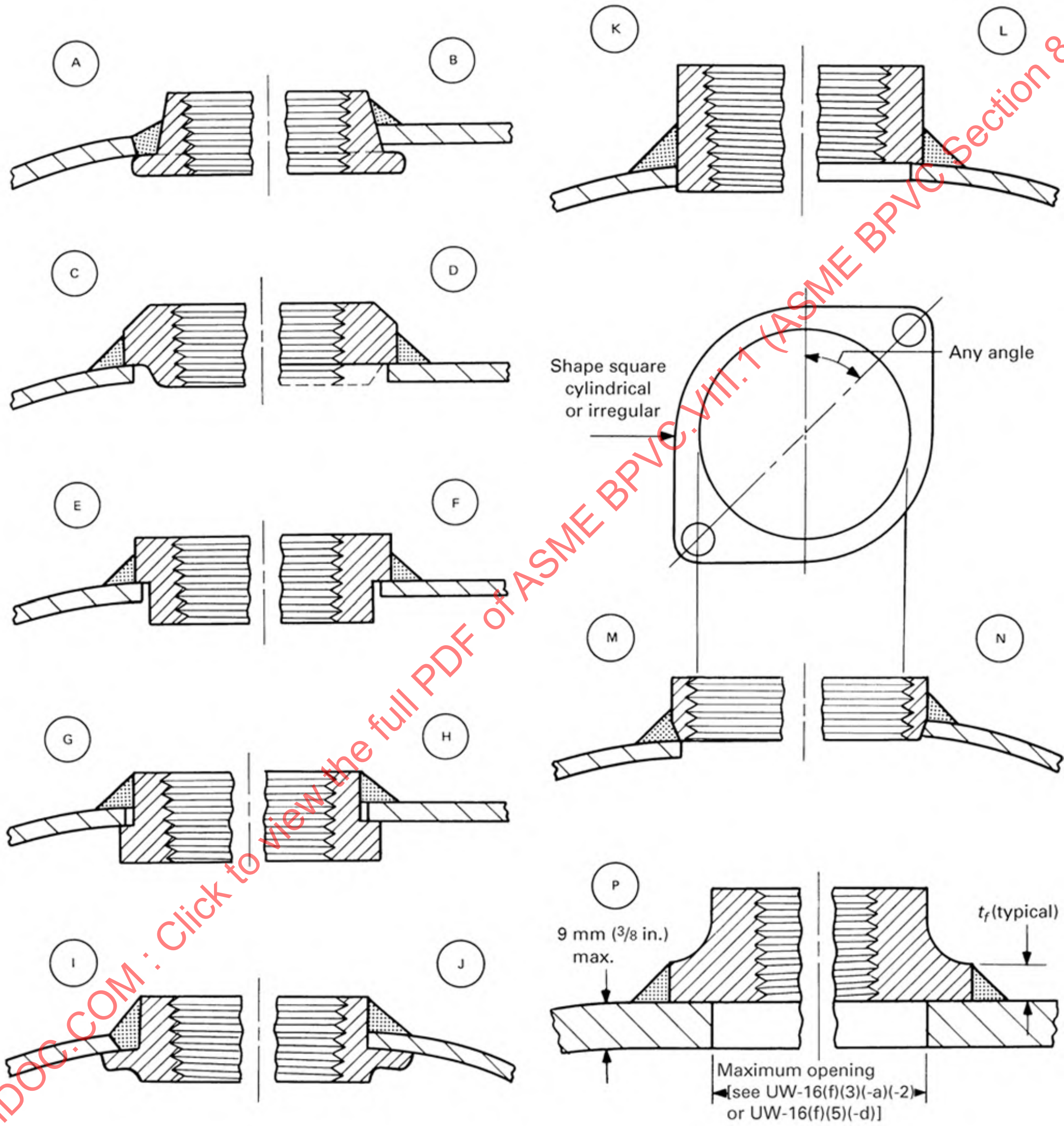
(-2) $^1/_4$ in. (6 mm) less than the bolting pad diameter for those that are attached to the outside of the vessel; see Figure UW-16.3, sketch (b)

(-c) The attachment weld throat shall be the greatest of the following:

(-1) the minimum nozzle neck thickness required by UG-45 for the same nominal size connection

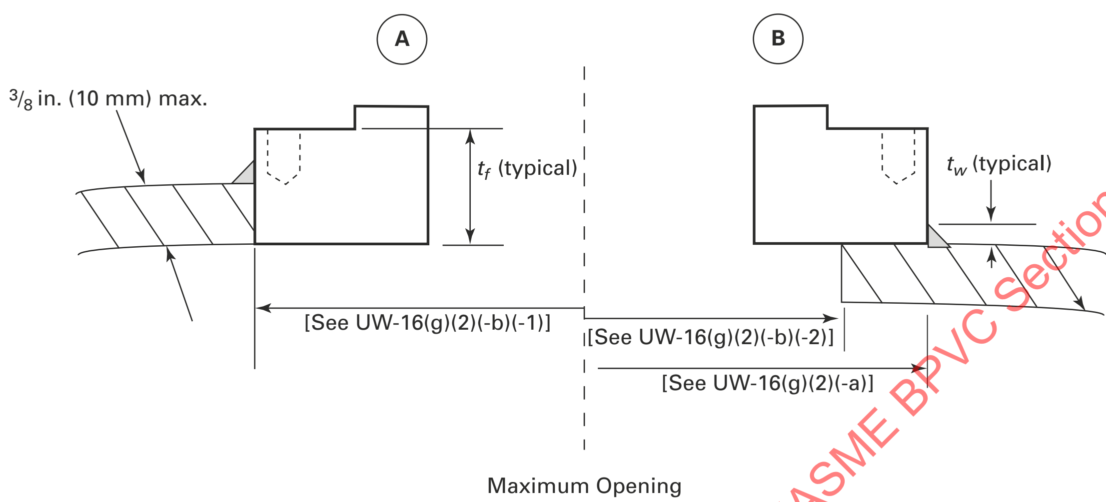
(-2) $1.0t_{min}$

Figure UW-16.2
Some Acceptable Types of Small Standard Fittings



GENERAL NOTE: See UW-16(f) for limitations.

Figure UW-16.3
Some Acceptable Types of Small Bolting Pads



GENERAL NOTE: See UW-16(g)(2) for limitations.

(-3) that necessary to satisfy the requirements of UW-18 for the applicable loadings of UG-22

(-d) The typical bolting pad dimension, t_f, as shown in Figure UW-16.3, sketch (a), shall be sufficient to accommodate a weld leg that will provide a weld throat dimension.

(-e) In satisfying the rules for reinforcement of openings, no material in the bolting pad shall be counted as reinforcement.

(3) If the opening exceeds the requirements of (2)(-b) above, or is greater than one-half the vessel inside diameter, the part of the vessel affected shall be subjected to a proof test as required in UG-36(a)(2), or the opening shall be reinforced in accordance with UG-37 and the nozzle or other connection attached, using a suitable detail in Figure UW-16.1, if welded.

(h) The minimum throat dimensions of fillet welds defined in Figure UW-16.1 shall be maintained around the circumference of the attachment, except as provided below.

(1) For nozzles attached to shells as shown in Figure UW-16.1, sketches (a) through (e), the fillet weld leg dimensions that meets the minimum throat dimensions shall be calculated for the equivalent thickness nozzle attached perpendicular to the surface of a flat head with thickness equal to the shell thickness.

(2) The fillet weld leg dimensions along the shell and nozzle need not exceed the calculated fillet weld leg dimension.

(3) For radial nozzles when the outside diameter of the nozzle approaches tangency with the shell, the fillet weld shall be smoothly transitioned into the full-penetration weld.

(4) For nonradial and tangential nozzles where the angle between the nozzle and shell is too large or too small to make a fillet weld or when the nozzle approaches tangency with the shell, the fillet weld shall be smoothly transitioned into the full-penetration weld.

UW-17 PLUG WELDS

(a) Plug welds may be used in lap joints, in reinforcements around openings and in nonpressure structural attachments. They shall be properly spaced to carry their proportion of the load, but shall not be considered to take more than 30% of the total load to be transmitted.

(b) Plug weld holes shall have a diameter not less than $t + 1/4$ in. (6 mm) and not more than $2t + 1/4$ in. (6 mm), where t is the thickness in inches of the plate or attached part in which the hole is made.

(c) Plug weld holes shall be completely filled with weld metal when the thickness of the plate, or attached part, in which the weld is made is $5/16$ in. (8 mm) or less; for thicker plates or attached parts the holes shall be filled to a depth of at least half the plate thickness or $5/16$ of the hole diameter, whichever is larger, but in no case less than $5/16$ in. (8 mm).

(d) The allowable working load on a plug weld in either shear or tension shall be computed by the following formula:

(U.S. Customary Units)

$$P = 0.63S\left(d - \frac{1}{4}\right)^2$$

(SI Units)

$$P = 0.63S(d - 6)^2$$

where

d = the bottom diameter of the hole in which the weld is made
P = total allowable working load on the plug weld
S = maximum allowable stress value for the material in which the weld is made (see UG-23)

UW-18 FILLET WELDS

(a) Fillet welds may be employed as strength welds for pressure parts within the limitations given elsewhere in this Division. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for the purposes enumerated in UG-55.

(c) Figures UW-13.1 and UW-13.2 show several construction details that are not permissible.

(d) Unless the sizing basis is given elsewhere in this Division, the maximum allowable load on fillet welds shall equal the product of the weld area (based on minimum leg dimension), the maximum allowable stress value in tension of the material being welded, and a joint efficiency of 55%.

UW-19 WELDED STAYED CONSTRUCTION

(a) Welded-in staybolts shall meet the following requirements:

(1) the arrangement shall substantially conform to one of those illustrated in Figure UW-19.1;

(2) the required thickness of the plate shall not exceed $1^1/_2$ in. (38 mm), except for Figure UW-19.1, sketches (e), (g), and (h). For plate thicknesses greater than $^3/_4$ in. (19 mm), the staybolt pitch shall not exceed the smaller of 20 in. (500 mm) or the limits established in UG-47(f).

(3) the provisions of UG-47 and UG-49 shall be followed; and

(4) the required area of the staybolt shall be determined in accordance with the requirements in UG-50.

(b) Welded stays, substantially as shown in Figure UW-19.2, may be used to stay jacketed pressure vessels provided:

(1) the pressure does not exceed 300 psi (2 MPa);

(2) the required thickness of the plate does not exceed $^1/_2$ in. (13 mm);

(3) the size of the fillet welds is not less than the plate thickness;

(4) the inside welds are properly inspected before the closing plates are attached;

(5) the allowable load on the fillet welds is computed in accordance with UW-18(d);

(6) the maximum diameter or width of the hole in the plate does not exceed $1^1/_4$ in. (32 mm);

(7) the welders are qualified under the rules of Section IX;

(8) the maximum spacing of stays is determined by the formula in UG-47(a), using C = 2.1 if either plate is not over $^7/_{16}$ in. (11 mm) thick, C = 2.2 if both plates are over $^7/_{16}$ in. (11 mm) thick.

(c) Welded stayed construction, as shown in Figure UW-19.2 or consisting of a dimpled or embossed plate welded to another like plate or to a plain plate, may be used, provided

(1) the welded attachment is made by fillet welds around holes or slots as shown in Figure UW-19.2 or if the thickness of the plate having the hole or slot is $^1/_2$ in. (12 mm) or less, and the hole is 1 in. (25 mm) or less in diameter, the holes may be completely filled with weld metal. The allowable load on the weld shall equal the product of the thickness of the plate having the hole or slot, the circumference or perimeter of the hole or slot, the allowable stress value in tension of the weaker of the materials being joined and a joint efficiency of 55%.

(2) the maximum allowable working pressure of the dimpled or embossed components is established in accordance with the requirements of UG-101. The joint efficiency, E, used in UG-101 to calculate the MAWP of the dimpled panel shall be taken as 0.80. This proof test may be carried out on a representative panel. If a representative panel is used, it shall be rectangular in shape and at least 5 pitches in each direction, but not less than 24 in. (600 mm) in either direction. The representative panel shall utilize the same weld details as will be used in the final construction.

(3) the plain plate, if used, shall meet the requirements for braced and stayed surfaces.

(d) The welds need not be radiographed, nor need they be postweld heat treated unless the vessel or vessel part in which they occur is required to be postweld heat treated.

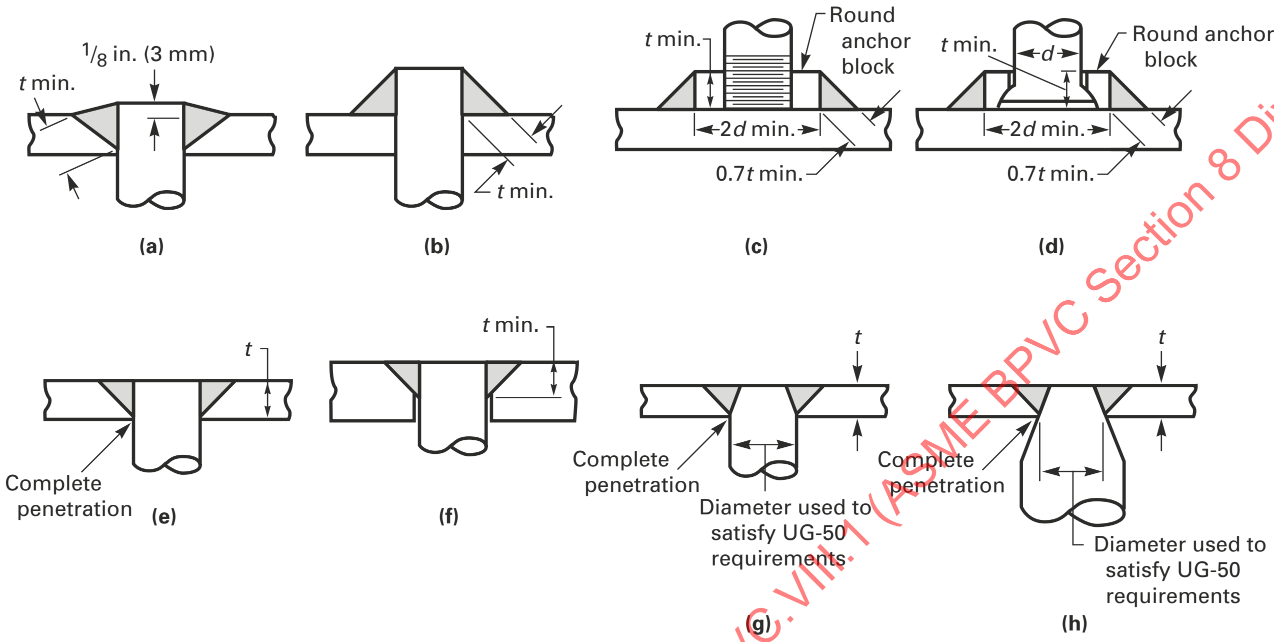
UW-20 TUBE-TO-TUBESHEET JOINT STRENGTH

UW-20.1 Scope. These rules provide a basis for establishing tube-to-tubesheet joint strength.

UW-20.1.1 General.

(a) Tubes used in the construction of heat exchangers or similar apparatus may be considered to act as stays, which support or contribute to the strength of the

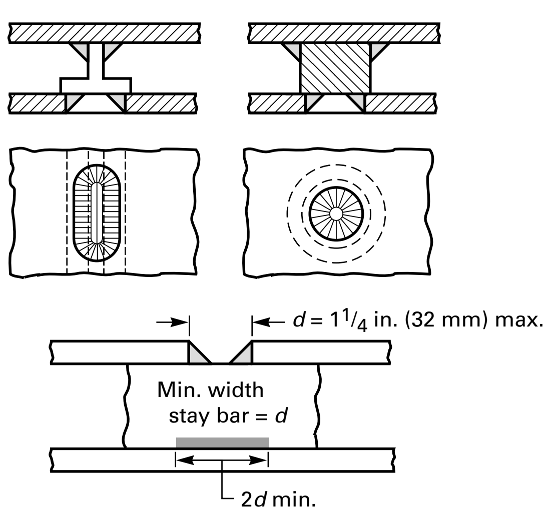
Figure UW-19.1
Typical Forms of Welded Staybolts



Legend:

t = nominal thickness of the thinner stayed plate

Figure UW-19.2
Use of Plug and Slot Welds for Staying Plates



tubesheets in which they are engaged. Tube-to-tubesheet joints shall be capable of transferring the applied tube loads. The design of tube-to-tubesheet joints depends on the type of joint, degree of examination, and shear load tests, if performed.

(b) Tube-to-tubesheet joints, except as exempted in (c) and (d) below, shall have their strength determined by either UW-20.3 or UW-20.4.

(c) Back-face welded joints, such as shown in Division 2, Figure 4.18.2(d) are not covered.

(d) Determination of tube-to-tubesheet joint strength is not mandatory for U-tube construction.

(e) Some combinations of tube and tubesheet materials, when welded, result in welded joints having lower ductility than required in the material specifications. Appropriate tube-to-tubesheet joint geometry, welding method, and/or heat treatment shall be used with these materials to minimize this effect.

(f) In the selection of joint type, consideration shall be given to the mean metal temperature of the joint at operating temperatures and differential thermal expansion of the tube and tubesheet that may affect the joint integrity. The following provisions apply for establishing maximum operating temperature for tube-to-tubesheet joints:

(1) Tube-to-tubesheet joints where the maximum allowable axial load is controlled by the weld shall be limited to the maximum temperature for which there are allowable stresses for the tube or tubesheet material in Section II, Part D, Subpart 1, Table 1A or Table 1B. Tube-to-tubesheet joints in this category are any of the following:

(-a) Those with or without expansion having full strength welds or partial strength welds designed in accordance with UW-20.3.

(-b) Those welded and expanded joints specified in Table UW-20.1, joint types f, g, and h, where the maximum allowable axial load is determined in accordance with UW-20.4 and is controlled by the weld ($f_{re} = f_{r(h)}$).

(-c) Those welded-only or welded and expanded joints specified in Table UW-20.1, joint types a, b, and e, where the maximum allowable load is determined in accordance with UW-20.4.

(2) Tube-to-tubesheet joints made by brazing specified in Table UW-20.1, joint types c and d, shall be limited to temperatures in conformance with the requirements of Part UB.

(3) Tube-to-tubesheet joints where the maximum allowable axial load is determined in accordance with UW-20.4 considering friction only as specified in Table UW-20.1, joint types i, j, and k, or is controlled by friction in a welded and expanded joint as specified in Table UW-20.1, joint types f, g, h (when $f_{re} = f_e\ f_r\ f_y\ f_T$) shall be limited to temperatures as determined by the following:

(-a) The operating temperature of the tube-to-tubesheet joint shall be within the tube and tubesheet time-independent properties of Section II, Part D, Subpart 1, Table 1A or Table 1B.

(-b) The maximum operating temperature is based on the interface pressure that exists between the tube and tubesheet and may be determined by either method below.

(-1) The maximum operating temperature is limited such that the interface pressure due to expanding the tube at joint fabrication plus the interface pressure due to differential thermal expansion, ($P_O + P_T$), does not exceed 58% of the smaller of the tube or tubesheet yield strength (see UG-23) at the operating temperature. When $P_T < 0$, where due to differential thermal expansion the tube expands less than the tubesheet, the maximum operating temperature is limited such that factor f_T remains of sufficient magnitude for the design loads. The interface pressure due to expanding the tube at fabrication or the interface pressure due to differential thermal expansion may be determined analytically or experimentally.

(-2) The maximum operating temperature may be determined by shear load tests described in UW-20.4.3. Two sets of specimens shall be tested. The first set shall be tested at the proposed operating temperature. The second set shall be tested at room temperature after heat soaking at the proposed operating temperature for 24 hr. The proposed operating temperature is acceptable if the provisions of UW-20.4.5 are satisfied.

(g) The Manufacturer shall prepare written procedures for joints that are expanded (whether welded and expanded or expanded only) for joint strength (see Nonmandatory Appendix HH). The Manufacturer shall establish the variables that affect joint repeatability in these procedures. The procedures shall provide detailed descriptions or sketches of enhancements, such as grooves, serrations, threads, and coarse machining profiles. The Manufacturer shall make these written procedures available to the Authorized Inspector.

UW-20.1.2 Definitions.

brazed-only joint: a tube-to-tubesheet joint that is made by brazing the end of the tube to the tubesheet. Brazed-only joints are subject to rules and service restrictions of Part UB.

expanded joint: a tube-to-tubesheet joint produced by applying an expanding force inside the portion of the tube to be engaged in the tubesheet in a manner that produces a determinable allowable axial joint load. The expanding force shall be set to values necessary to effect sufficient residual interface pressure between the tube and hole for joint strength.

Table UW-20.1
Efficiencies, f_r

Joint Type	Description [Note (1)]	Notes	$f_{r,\text{Test}}$ [Note (2)]	$f_{r,\text{No Test}}$
a	Welded only, total weld size $(0.7a_f + a_g) \geq t$	(4)	1.00	...
b	Welded only, total weld size $(0.7a_f + a_g) < t$	(4)	0.70	...
c	Brazed, examined	(5)	1.00	0.80
d	Brazed, not fully examined	(6)	0.50	0.40
e	Welded, total weld size $(0.7a_f + a_g) \geq t$, and expanded	(3)	1.00	0.80
f	Welded, total weld size $(0.7a_f + a_g) < t$, and expanded, enhanced with two or more grooves	(3) (7) (8) (9) (10)	0.95	0.75
g	Welded, total weld size $(0.7a_f + a_g) < t$, and expanded, enhanced with single groove	(3) (7) (8) (9) (10)	0.85	0.65
h	Welded, total weld size $(0.7a_f + a_g) < t$, and expanded, not enhanced	(3) (7) (8)	0.70	0.50
i	Expanded, enhanced with two or more grooves	(7) (8) (9) (10)	0.90	0.70
j	Expanded, enhanced with single groove	(7) (8) (9) (10)	0.80	0.65
k	Expanded, not enhanced	(7) (8)	0.60	0.50

GENERAL NOTE: The joint efficiencies listed in this table apply only to allowable loads and do not indicate the degree of joint leak tightness.

NOTES:
(1) For joint types involving more than one fastening method, the sequence used in the joint description does not necessarily indicate the order in which the operations are performed.
(2) The use of the $f_{r,\text{test}}$ factor requires qualification in accordance with UW-20.4.3 and UW-20.4.4.
(3) The value of $f_{r,\text{no test}}$ applies only to material combinations as provided for under Section IX. For material combinations not provided for under Section IX, f_r shall be determined by test in accordance with UW-20.4.3 and UW-20.4.4.
(4) $f_{r,\text{no test}}$ is not permitted for welded only joint types in accordance with UW-20.4.3, refer to UW-20.4.2.
(5) A value of 1.00 for $f_{r,\text{test}}$ or 0.80 for $f_{r,\text{no test}}$ can be applied only to joints in which visual examination assures that the brazing filler metal has penetrated the entire joint [see UB-14(a)] and the depth of penetration is not less than 3 times the nominal thickness of the tube wall.
(6) A value of 0.50 for $f_{r,\text{test}}$ or 0.40 for $f_{r,\text{no test}}$ shall be used for joints in which visual examination will not provide proof that the brazing filler metal has penetrated the entire joint [see UB-14(b)].
(7) If $d_o/(d_o - 2t)$ is less than 1.05 or greater than 1.410, f_r shall be determined by test in accordance with UW-20.4.3 and UW-20.4.4.
(8) If the nominal pitch (center-to-center distance of adjacent tube holes) is less than $d_o + 2t$, f_r shall be determined by test in accordance with UW-20.4.3 and UW-20.4.4.
(9) The Manufacturer may use other means to enhance the strength of expanded joints, provided, however, that the joints are tested in accordance with UW-20.4.3 and UW-20.4.4.
(10) For explosive and hydraulic expansion, grooves shall be a minimum of 1.1 $[(d_o - t)t]^{0.5}$ wide. For explosively or hydraulically expanded joints with single grooves meeting this requirement, f_r for joint type f may be used in lieu of that for joint type g, and f_r for joint type i may be used in lieu of that for joint type j, as applicable.

full strength weld: a full strength tube-to-tubesheet weld is one in which the design strength is equal to or greater than the axial tube strength, F_t. When the weld in a tube-to-tubesheet joint meets the requirements of UW-20.3.2, it is a full-strength weld, and the joint does not require qualification by shear load testing. Such a weld also provides tube joint leak tightness.

partial strength weld: a partial strength weld is one in which the design strength is based on the mechanical and thermal axial tube loads (in either direction) that are determined from the actual design conditions. The maximum allowable axial load of this weld may be determined in accordance with UW-20.3 or UW-20.4. When the weld meets the requirements of UW-20.3, the joint does not require qualification by shear load testing. Such a weld also provides tube joint leak tightness.

seal weld: a tube-to-tubesheet seal weld is one used to supplement an expanded tube joint to ensure leak tightness. Its size has not been determined based on axial tube loading.

tube hole enhancement: a groove or other modification of the tube hole surface that increases the allowable axial joint load

welded-and-expanded joint: a tube-to-tubesheet joint that is made by both welding and expanding.

welded-only joint: a tube-to-tubesheet joint that is made by welding the end of the tube to the tubesheet.

(25) **UW-20.2 Nomenclature.**

a_c = length of the combined weld(s) measured parallel to the longitudinal axis of the tube at its outside diameter. For fillet only welds, $a_c = a_f$. For groove only welds, $a_c = a_g$. These dimensions are illustrated in Figures UW-20.1 and UW-20.2.

a_f = fillet weld leg. For unequal leg fillets, a_f shall be the size of the smaller of the two legs.

a_g = depth of groove weld. Depth can be achieved by chamfer or nonchamfer groove.

a_r = minimum required length of the weld(s) under consideration

A_t = tube cross-sectional area

d_i = nominal tube inside diameter

d_o = nominal tube outside diameter

E = modulus of elasticity for tubesheet material at T

E_t = modulus of elasticity for tube material at T

F_d = design strength, but not greater than F_t

f_d = ratio of the design strength to the tube strength

f_e = factor for the length of the expanded portion of the tube

F_f = fillet weld strength, but not greater than F_t

f_f = ratio of the fillet weld strength to the design strength

F_g = groove weld strength, but not greater than F_t

f_g = ratio of the groove weld strength to the design strength

f_r = factor to define the efficiency of joint, set equal to the value of $f_{r,\text{test}}$ or $f_{r,\text{no test}}$

$f_{r,\text{test}}$ = factor to define efficiency of joint established by shear load test. Equal to the value calculated from results of test in accordance with UW-20.4.4 or as tabulated in Table UW-20.1, whichever is less, except as permitted in UW-20.4.3.11.

$f_{r,\text{no test}}$ = factor to define efficiency of joint without shear load test in accordance with Table UW-20.1

f_{re} = factor for the overall efficiency of welded and expanded joints. Larger of the efficiency of the welded alone and net efficiency of the welded and expanded joint

F_t = axial tube strength

f_T = factor to account for the increase or decrease of tube joint strength due to radial differential thermal expansion at the tube-to-tubesheet joint. Acceptable values of f_T may range from 0 to greater than 1. When the f_T value is negative, it shall be set to 0.

f_w = weld strength factor

f_y = factor for differences in the mechanical properties of tubesheet and tube materials

k = tube load factor
= 1.0 for loads due to pressure-induced axial forces
= 1.0 for loads due to thermally induced or pressure plus thermally induced axial forces on welded-only joints where the thickness through the weld throat $(0.7a_f + a_g)$ is less than the nominal tube wall thickness t
= 2.0 for loads due to thermally induced or pressure plus thermally induced axial forces on all other tube-to-tubesheet joints

l = length of the expanded portion of the tube

$L_{\max}$ = maximum allowable axial load in either direction on the tube-to-tubesheet joint

L_{test} = axial load at which failure of the test specimens occur

$L_{1,\text{test}}$ = lowest axial load at which failure occurs at operating temperature

$L_{2,\text{test}}$ = lowest axial load at which failure of heat-soaked specimen tested at room temperature occurs

P_e = tube expanding pressure

P_o = interface pressure between the tube and tubesheet that remains after expanding the tube at fabrication. This pressure may be established analytically or experimentally.

P_T = interface pressure between the tube and tubesheet due to differential thermal growth. This pressure may be established analytically or experimentally.

R_m = mean tube radius

r_o = tube outside radius

S = allowable stress for the tube material at design temperature. For a welded tube or pipe, use the allowable stress for the equivalent seamless product. When the allowable stress for the equivalent seamless product is not available, divide the allowable stress of the welded product by 0.85.

S_T = tensile strength for the tube material from the material test report

S_t = allowable stress of the material to which the tube is welded. See UW-20.5(d).

S_u = tensile strength for tube material at operating temperature taken from Section II, Part D, Subpart 1, Table U

S_{ua} = tensile strength for tube material at room temperature taken from Section II, Part D, Subpart 1, Table U

S_w = allowable stress in weld

S_y = yield strength for tubesheet material at tubesheet design temperature, T (see UG-23)

$S_{y,a}$ = yield strength for tubesheet material at ambient temperature, T_a (see UG-23)

$S_{y,t}$ = yield strength for tube material at tubesheet design temperature, T (see UG-23)

$S_{y,t,a}$ = yield strength for tube material at ambient temperature, T_a (see UG-23)
T = tubesheet design temperature
t = nominal tube wall thickness
T_a = ambient temperature
α = mean coefficient of thermal expansion of tubesheet material at T
α_t = mean coefficient of thermal expansion of tube material at T

UW-20.3 Joint Strength by Calculation.

UW-20.3.1 Scope. These rules provide a basis for establishing weld sizes and allowable joint loads by calculation for full strength and partial strength tube-to-tubesheet welds. These rules apply to welded only joints and welded and expanded joints in which the strength of the expansion is not considered. These rules cover the welds shown in Figure UW-20.1

UW-20.3.2 Full Strength Welds. Full-strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a full-strength weld shall be determined in accordance with UW-20.3.4.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a full-strength weld shall be $L_{max} = kF_t$.

UW-20.3.3 Partial Strength Welds. Partial-strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a partial-strength weld shall be determined in accordance with UW-20.3.4.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a partial-strength weld shall be $L_{max} = k(F_f + F_g)$, but not greater than kF_t.

(25) **UW-20.3.4 Weld Size Design Equations.**

(a) The size of tube-to-tubesheet strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(1) For fillet welds shown in sketch (a)

(-a) calculate the minimum required length of the fillet weld leg

$$a_r = \sqrt{(0.75d_o)^2 + 2.73t(d_o - t)f_w f_d} - 0.75d_o$$

(-b) for full strength welds, $a_f \geq \max(a_r, 1.4t)$

(-c) for partial strength welds, $a_f \geq a_r$

(2) For groove welds shown in sketch (b)

(-a) calculate the minimum required length of the groove weld leg

$$a_r = \sqrt{(0.75d_o)^2 + 1.76t(d_o - t)f_w f_d} - 0.75d_o$$

(-b) for full strength welds, $a_g \geq \max(a_r, t)$

(-c) for partial strength welds, $a_g \geq a_r$

(3) For combined groove and fillet welds shown in sketch (c), where $a_f = a_g$

(-a) calculate the minimum required length of the combined weld legs

$$a_r = 2\left[\sqrt{(0.75d_o)^2 + 1.07t(d_o - t)f_w f_d} - 0.75d_o\right]$$

(-b) for full strength welds, $a_c \geq \max[a_r, 1.2t]$

(-c) for partial strength welds, $a_c \geq a_r$

(-d) calculate a_f and a_g

$$a_f = a_c/2$$

$$a_g = a_c/2$$

(4) For combined groove and fillet welds shown in sketch (d), where a_f is not equal to a_g

(-a) choose a_g and calculate the minimum required length of the fillet weld leg

$$a_r = \sqrt{(0.75d_o)^2 + 2.73t(d_o - t)f_w f_d f_f} - 0.75d_o$$

(-b) for full strength welds, $a_c \geq \max[(a_r + a_g), (1.4t - 0.4a_g)]$

(-c) for partial strength welds, $a_c \geq (a_r + a_g)$

(-d) calculate a_f

$$a_f = a_c - a_g$$

(5) For inset fillet welds shown in sketch (e)

(-a) calculate the minimum required length of the fillet weld leg

$$a_r = 0.75d_o - \sqrt{(0.75d_o)^2 - 2.73t(d_o - t)f_w f_d}$$

(-b) full strength welds are not possible with this configuration

(-c) for partial strength welds, $t \geq a_f \geq a_r$. If $a_r > t$, joint load cannot be calculated in accordance with this section. See UW-20.4.

(6) For combined groove and inset fillet welds shown in sketch (f)

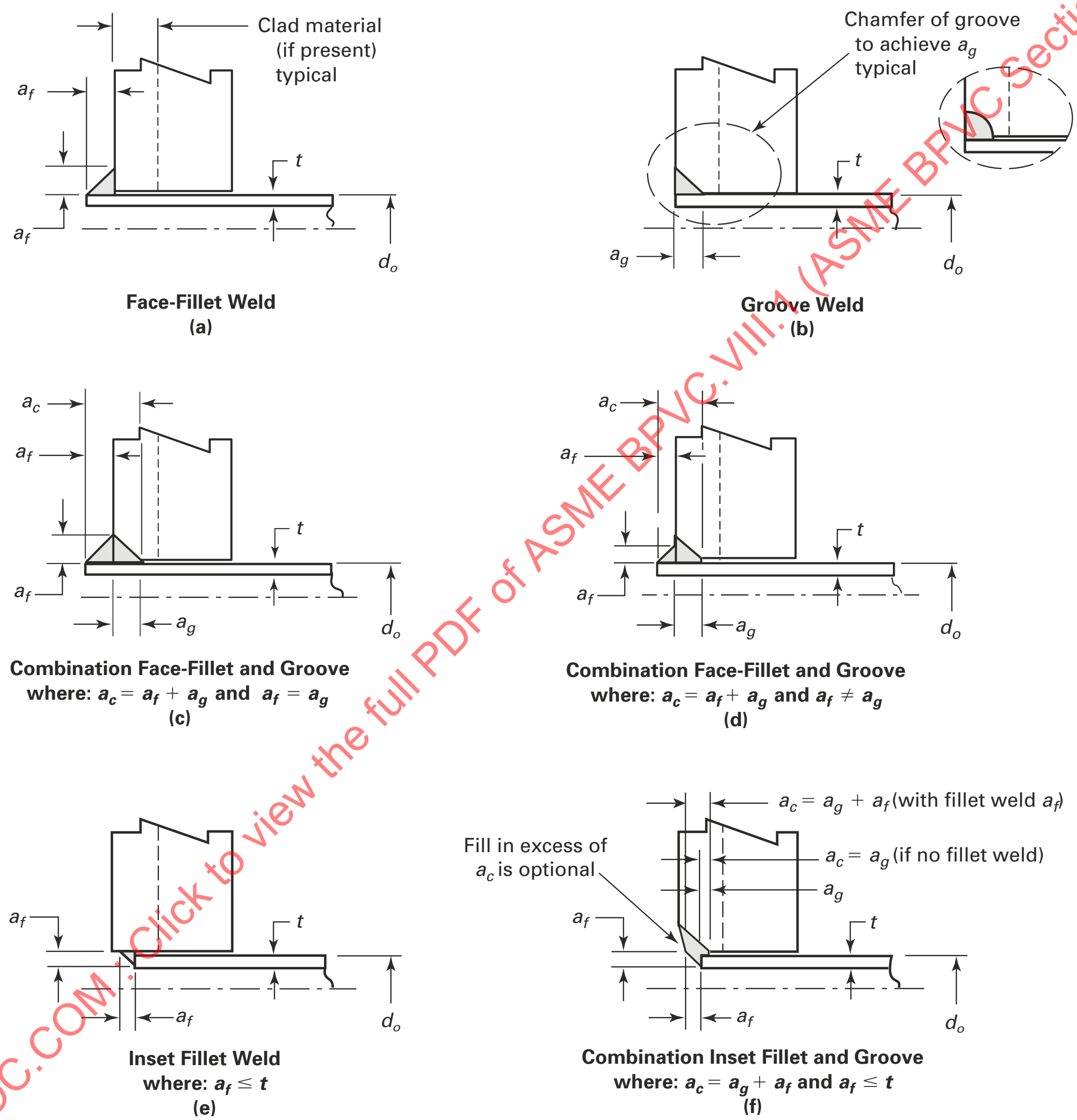
(-a) choose a_f and calculate the minimum required length of the groove weld leg

$$a_r = \sqrt{(0.75d_o)^2 + 1.76t(d_o - t)f_w f_d f_g} - 0.75d_o$$

(-b) for full strength welds, $a_c \geq \max[(a_r + a_f), (t + 0.3a_f)]$

(-c) for partial strength welds, $a_c \geq (a_r + a_f)$

Figure UW-20.1
Tube-to-Tubesheet Joints Acceptable to Determine Joint Strength by Calculation



Face-Fillet Weld
(a)

Groove Weld
(b)

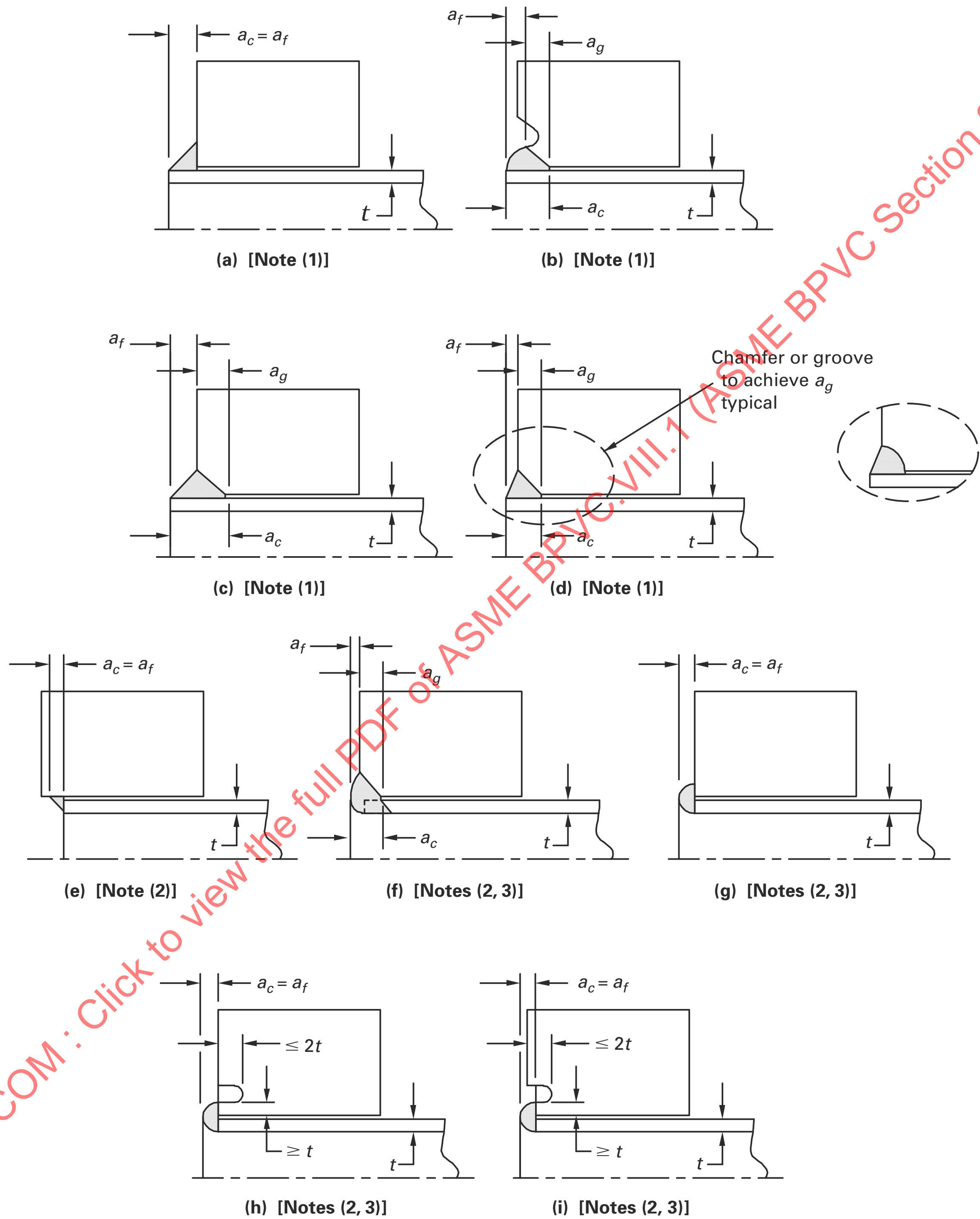
Combination Face-Fillet and Groove
where: $a_c = a_f + a_g$ and $a_f = a_g$
(c)

Combination Face-Fillet and Groove
where: $a_c = a_f + a_g$ and $a_f \neq a_g$
(d)

Inset Fillet Weld
where: $a_f \leq t$
(e)

Combination Inset Fillet and Groove
where: $a_c = a_g + a_f$ and $a_f \leq t$
(f)

Figure UW-20.2
Some Acceptable Types of Tube-to-Tubesheet Welds



NOTES:
(1) Sketches (a) through (d) show some acceptable weld geometries where thickness through the weld throat may be sized ≥ t.
(2) Sketches (e) through (i) show some acceptable weld geometries where thickness through the weld throat is less than t.
(3) For these geometries where weld length cannot be established by dimensions prior to weld, dimension a_c shall be verified during WPS qualification per Section, IX, QW-193 and design strength shall be calculated in accordance with UW-20.4.

(b) Weld strength factors used in (a) above shall be calculated using the following equations:

$$f_f = 1 - \frac{F_g}{f_d F_t}$$

$$f_g = 1 - \frac{F_f}{f_d F_t}$$

$$f_w = \frac{S}{S_w}$$

where

f_d = 1.0 for full strength welds
= F_d/F_t for partial strength welds
F_f = $\min[0.55\pi a_f(d_o + 0.67a_f)S_w, F_t]$ for face fillet welds as shown in Figure UW-20.1, sketches (a), (c), and (d)
= $\min[0.55\pi a_f(d_o - 0.67a_f)S_w, F_t]$ for inset fillet welds as shown in Figure UW-20.1, sketches (e) and (f)
F_g = $\min[0.85\pi a_g(d_o + 0.67a_g)S_w, F_t]$
F_t = $\pi t(d_o - t)S$
S_w = $\min(S, S_t)$

UW-20.4 Joint Strength by Factors.

UW-20.4.1 Scope. These rules provide a basis for establishing allowable joint loads using strength factors. Some acceptable geometries and combinations of brazed, welded, and mechanical joints are described in Table UW-20.1. Some acceptable types of welded joints are illustrated in Figure UW-20.2.

(a) Geometries, including variations in tube pitch, fastening methods, and combinations of fastening methods not described or shown may be used provided qualification tests have been conducted and applied in compliance with the procedures set forth in UW-20.4.3 and UW-20.4.4

(b) Materials for welded or brazed tube-to-tubesheet joints that do not meet the requirements of UW-5 or UB-5, but in all other respects meet the requirements of this Division, may be used if qualification tests of the tube-to-tubesheet joint have been conducted and applied in compliance with the procedures set forth in UW-20.4.3 and UW-20.4.4.

(25) **UW-20.4.2 Maximum Axial Loads.**

(a) The maximum allowable axial load in either direction on tube-to-tubesheet joints shall be determined in accordance with the following:

(1) For joint types a, b, c, d, and e

$$L_{max} = kA_t S f_r$$

(2) For joint types f, g, and h

$$L_{max} = \min\left(kA_t S f_{re},\ kA_t S\right)$$

(3) For joint types i, j, and k

$$L_{max} = \min\left(kA_t S f_e f_r f_y f_T,\ kA_t S\right)$$

where

A_t = $\pi(d_o - t)t$
f_e = $\min[(l/d_o), 1.0]$ for tube joints made with expanded tubes in tube holes without enhancement
= 1.0 for tube joints made with expanded tubes in tube holes with enhancement
f_{re} = $\max[(f_e f_r f_y f_T), f_{r(h)}]$
$f_{r(h)}$ = 0.70 when established by shear load test per UW-20.4.4
= 0.50 without shear load test
f_y = $\min[(S_y/S_{y,t}), 1.0]$ for expanded joints. When f_y < 0.60, qualification of joint by shear load test is required

$$f_T = \max\left[0, \frac{P_o + P_T}{P_o}\right]$$

(b) P_o, P_T may be established experimentally or analytically. The following equations may be used to calculate P_o and P_T:

$$P_e = S_{y,t,a}\frac{t + r_o\left(\frac{S_{y,a}}{S_{y,t,a}}\right)}{t + r_o}\left(1.945 - 1.384\frac{d_i}{d_o}\right)$$

$$P_o = P_e\left[1 - \left(\frac{d_i}{d_o}\right)^2\right] - \frac{2}{\sqrt{3}}S_{y,t,a}\left(\ln\frac{d_o}{d_i}\right)$$

$$P_T = \frac{\frac{R_m}{d_o}E_t\left[\alpha_t d_o\left(T - T_a\right) - \alpha d_o\left(T - T_a\right)\right]}{\left(\frac{d_o{}^2}{t} - R_m\right) + R_m\left(2.9\frac{E_t}{E} - 0.3\right)}$$

$$R_m = r_o - \frac{t}{2}$$

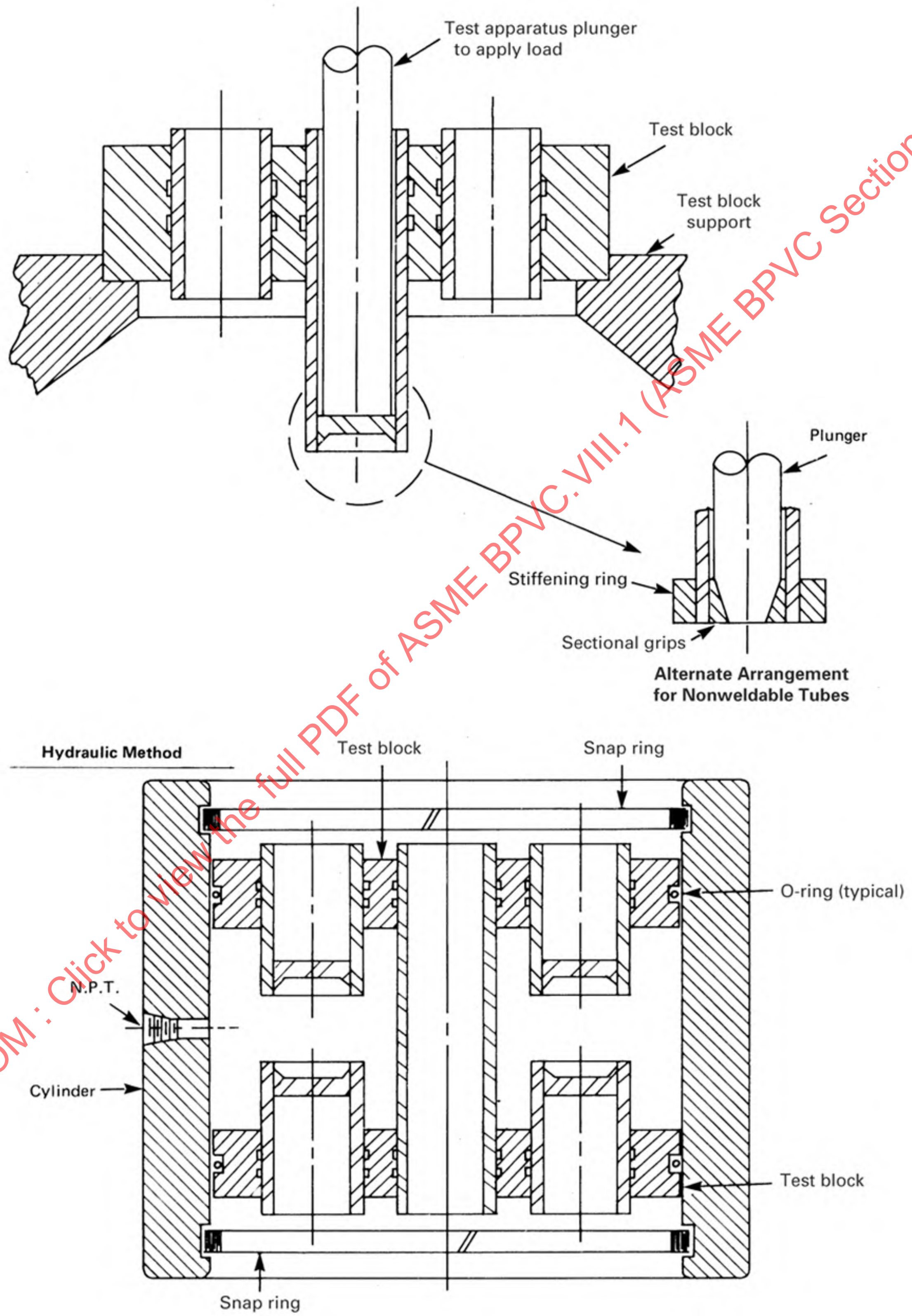
UW-20.4.3 Shear Load Test.

UW-20.4.3.1 Flaws in the specimen may affect results. If any test specimen develops flaws, the retest provisions of UW-20.4.3.11 below shall govern.

UW-20.4.3.2 If any test specimen fails because of mechanical reasons, such as failure of testing equipment or improper specimen preparation, it may be discarded, and another specimen taken from the same heat.

UW-20.4.3.3 The shear load test subjects a full-size specimen of the tube joint under examination to a measured load sufficient to cause failure. In general, the testing equipment and methods are given in ASTM E8. Additional fixtures for shear load testing of tube-to-tubesheet joints are shown in Figure UW-20.3.

Figure UW-20.3 (25)
Typical Test Fixtures for Expanded or Welded Tube-to-Tubesheet Joints



UW-20.4.3.4 The test block simulating the tubesheet may be circular, square, or rectangular in shape, essentially in general conformity with the tube pitch geometry. The test assembly shall consist of an array of tubes such that the tube to be tested is in the geometric center of the array and surrounded by at least one row of adjacent tubes. The test block shall extend a distance of at least one tubesheet ligament beyond the edge of the peripheral tubes in the assembly.

UW-20.4.3.5 All tubes in the test block array shall be from the same heat and shall be installed using identical procedures.

(a) The finished thickness of the test block may be less but not greater than the tubesheet it represents. For expanded joints, made with or without welding, the expanded area of the tubes in the test block may be less but not greater than that for the production joint to be qualified.

(b) The length of the tube used for testing the tube joint need only be sufficient to suit the test apparatus. The length of the tubes adjacent to the tube joint to be tested shall not be less than the thickness of the test block to be qualified.

UW-20.4.3.6 The procedure used to prepare the tube-to-tubesheet joints in the test specimens shall be the same as used for production.

UW-20.4.3.7 The tube-to-tubesheet joint specimens shall be loaded until mechanical failure of the joint or tube occurs. The essential requirement is that the load be transmitted axially.

UW-20.4.3.8 Any speed of testing may be used, provided load readings can be determined accurately.

UW-20.4.3.9 The reading from the testing device shall be such that the applied load required to produce mechanical failure of the tube-to-tubesheet joint can be determined.

UW-20.4.3.10 For determining $f_{r,\text{test}}$ for joint types listed in Table UW-20.1, a minimum of three specimens shall constitute a test. The value of $f_{r,\text{test}}$ shall be calculated in accordance with UW-20.4.4 using the lowest value of L_{test}. In no case shall the value of $f_{r,\text{test}}$ using a three specimen test exceed the value of $f_{r,\text{test}}$ given in Table UW-20.1. If the value of $f_{r,\text{test}}$ so determined is less than the value for $f_{r,\text{test}}$ given in Table UW-20.1, retesting may be performed in accordance with UW-20.4.3.11, or a new three specimen test may be performed using a new joint configuration or fabrication procedure. All previous test data shall be rejected. To use a value of $f_{r,\text{test}}$ greater than the value given in Table UW-20.1, a nine-specimen test shall be performed in accordance with UW-20.4.3.11.

UW-20.4.3.11 For joint types not listed in Table UW-20.1, to increase the value of $f_{r,\text{test}}$ for joint types listed in Table UW-20.1, or to retest joint types listed in Table UW-20.1, the tests to determine $f_{r,\text{test}}$ shall conform to the following:

(a) A minimum of nine specimens from a single tube shall be tested. Additional tests of specimens from the same tube are permitted, provided all test data are used in the determination of $f_{r,\text{test}}$. If a change in the joint design or its manufacturing procedure is necessary to meet the desired characteristics, complete testing of the modified joint shall be performed.

(b) In determining the value of $f_{r,\text{test}}$, the mean value of L_{test} shall be determined and the standard deviation, sigma, about the mean shall be calculated. The value of $f_{r,\text{test}}$ shall be calculated using the value of L_{test} corresponding to −2sigma , using the applicable equation in UW-20.4.4. In no case shall $f_{r,\text{test}}$ exceed 1.0.

UW-20.4.3.12 Once shear load tests have been successfully completed for a tube-to-tubesheet joint design, the Manufacturer that produced the test specimen may use the calculated $f_{r,\text{test}}$ for any production tube-to-tubesheet joint design that the Manufacturer produces having the same geometry, material nominal composition, specified ultimate tensile strength, and fabrication procedure used for the shear load test specimen. The fabrication procedure shall contain or reference the test qualification information required by HH-5.2 and/or Section IX, QW-202.6, as applicable.

UW-20.4.4 Acceptance Standards for Joint Efficiency Factor Determined by Test.

UW-20.4.4.1 The value of $f_{r,\text{test}}$ determined by testing shall be calculated as follows:

(a) For joint types a, b, c, d, and e

$$f_{r,\text{test}} = \frac{L(\text{test})}{A_t S_T}$$

(b) For joint types f, g, h, i, j, and k

$$f_{r,\text{test}} = \frac{L(\text{test})}{A_t S_T f_e f_y}$$

UW-20.4.4.2 The value of $f_{r,\text{test}}$ shall be used for f_r in the equation for $L_{\max}$.

UW-20.4.5 Acceptance Standards for Proposed Operating Temperatures Determined by Test. The proposed operating conditions shall be acceptable if both of the following conditions are satisfied:

$$L_{1(\text{test})} \geq A_t f_e f_y S_T (S_u / S_{ua})$$

$$L_{2(\text{test})} \geq A_t f_e f_y S_T$$

UW-20.5 Clad Tubesheets.

(a) Tube-to-tubesheet welds in the cladding of either integral or weld metal overlay clad tubesheets may be considered strength welds (full or partial), provided the welds meet the design requirements of UW-20. In addition, when the strength welds are to be made in the clad material of integral clad tubesheets, the integral clad material to be used for tubesheets shall meet the requirements in (1) and (2) for any combination of clad and base materials. The shear strength test and ultrasonic examination specified in (1) and (2) are not required for weld metal overlay clad tubesheets.

(1) Integral clad material shall be shear strength tested in accordance with SA-263. One shear test shall be made on each integral clad plate or forging and the results shall be reported on the material test report.

(2) Integral clad material shall be ultrasonically examined for bond integrity in accordance with SA-578, including Supplementary Requirement S1, and shall meet the acceptance criteria given in SA-263 for Quality Level Class 1.

(b) When the design calculations for clad tubesheets are based on the total thickness including the cladding, the clad material shall meet any additional requirements specified in Part UCL.

(c) When tubesheets are constructed using linings, or integral cladding that does not meet the requirements of (a)(1) and (a)(2), the strength of the tube-to-tubesheet joint shall not be dependent upon the connection between the tubes and the lining or integral cladding, as applicable.

(d) When the tubes are strength welded (full or partial) to integral or weld metal overlay clad tubesheets, S_t shall be the allowable stress value of the integral cladding or the wrought material whose chemistry most closely approximates that of the weld metal overlay cladding. The thickness of the integral or weld metal clad overlay material shall be sufficient to prevent any of the strength weld from extending into the base material.

UW-21 ASME B16.5 SOCKET AND SLIP-ON FLANGE WELDS

(a) ASME B16.5 socket weld flanges shall be welded using an external fillet weld. See Figure UW-21, sketch (4).

(b) ASME B16.5 slip-on flanges shall be welded using an internal and an external weld. See Figure UW-21, sketches (1), (2), and (3).

(c) Nomenclature

t_n = nominal thickness of the shell or nozzle
X_{min} = the lesser of $1.4t_n$ or the thickness of the hub

(d) When ASME B16.5 slip-on flanges are shown to comply with all the requirements provided in Mandatory Appendix 2 of this Division, the weld sizes in Mandatory Appendix 2 may be used as an alternative to the requirements in (b).

FABRICATION

UW-26 GENERAL (25)

(a) The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsections C and D.

(b) Each Manufacturer or parts Manufacturer shall be responsible for the quality of the welding done by its own organization and shall conduct tests not only of the welding procedure to determine its suitability to ensure welds that will meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly.

The Manufacturer's Quality Control System shall include a requirement for complete and exclusive administrative and technical supervision and control of all welders and welding operators, whether direct employees or those engaged by contract for their services.

(c) No production welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with Section IX shall be used in production.

(d) The Manufacturer (Certificate Holder) may engage individuals by contract or agreement for their services as welders[46] at the shop location shown on the Certificate of Authorization and at field sites (if allowed by the Certificate of Authorization) for the construction of pressure vessels or vessel parts, provided all of the following conditions are met:

(1) All Code construction shall be the responsibility of the Manufacturer.

(2) All welding shall be performed in accordance with the Manufacturer's Welding Procedure Specifications in accordance with the requirements of Section IX.

(3) All welders shall be qualified by the Manufacturer in accordance with the requirements of Section IX.

(4) The Manufacturer's Quality Control System shall include as a minimum:

(-a) evidence of the Manufacturer's authority to assign and remove welders without involvement of any other organization;

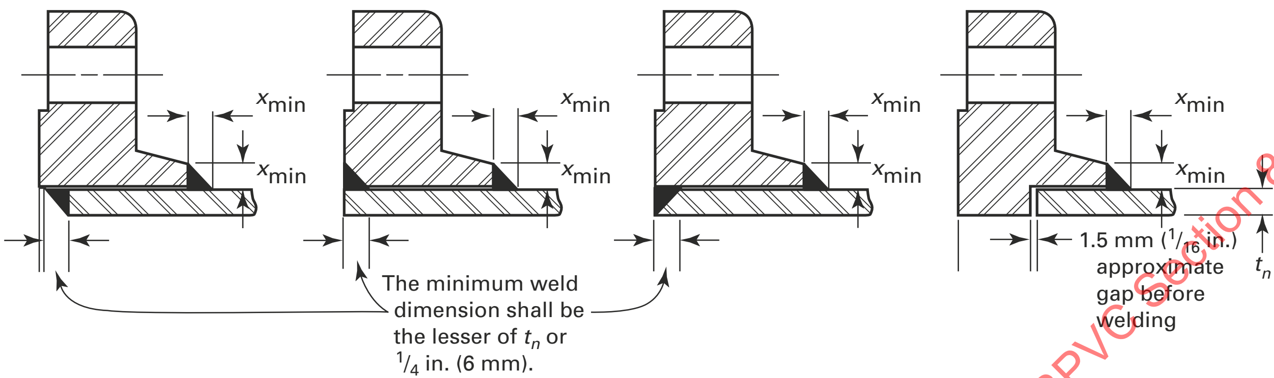
(-b) a requirement for assignment of welder identification symbols;

(-c) evidence that this program has been accepted by the Manufacturer's Authorized Inspection Agency which provides the inspection service.

(5) The Manufacturer shall be responsible for Code compliance of the vessel or part, including Certification Mark stamping and providing Data Report Forms properly executed and countersigned by the Inspector.

(25)

Figure UW-21
Typical Details for Slip-On and Socket Welded Flange Attachment Welds



UW-27 WELDING PROCESSES

The welding processes that may be used in the construction of vessels under this Part of this Division are limited to those listed in Section IX, Article II with the following additional restrictions:

(a) Other than pressure inherent to the welding processes, no mechanical pressure or blows shall be applied except as permitted for peening in UW-39.

(b) Arc stud welding and resistance stud welding may be used only for non-pressure-bearing attachments having a load- or non-load-carrying function, except for material listed in Table UHT-23, provided that, in the case of ferrous materials, the heat treatment requirements of UCS-56 are complied with and the requirements of UW-28(b) and UW-29(a) are met prior to start of production welding. Studs shall be limited to 1 in. (25 mm) diameter maximum for round studs and an equivalent cross-sectional area for studs with other shapes.

(c) The electroslag welding process may be used for butt welds only in ferritic steels and austenitic stainless steels of types listed in UW-5(d), provided the requirements of UW-11(a)(6) and UW-11(d) are satisfied. [See UW-5(e).]

(d) The electrogas welding process may be used for butt welds only in ferritic steels and austenitic stainless steels of types listed in UW-5(d), provided the requirements of UW-11(a)(6) are satisfied. When a single pass is greater than $1\frac{1}{2}$ in. (38 mm) in ferritic materials, the joint shall be given a grain refining (austenitizing) heat treatment. [See UW-5(e).]

(e) Welding processes accepted under Section IX Code Cases shall not be used unless those Code Cases are explicitly accepted by this Division.

UW-28 QUALIFICATION OF WELDING PROCEDURE (25)

(a) Each welding procedure used in joining pressure parts to pressure parts or joining pressure parts to load-carrying nonpressure parts, such as all permanent or temporary clips and lugs to pressure parts, shall be recorded in detail by the Manufacturer and qualified in accordance with the rules of Section IX.

(b) Tube-to-tubesheet welding shall be qualified in accordance with Section IX, QW-193 or QW-202.6.

(c) The procedure used in welding non-pressure-bearing attachments which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.), to pressure parts shall meet the following requirements.

(1) When the welding process is manual, machine, or semiautomatic, procedure qualification is required in accordance with Section IX.

(2) When the welding is any automatic welding process performed in accordance with a Welding Procedure Specification (in compliance with Section IX as far as applicable), procedure qualification testing is not required.

(d) Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. Alternatively, AWS Standard Welding Procedure Specifications that have been accepted by Section IX may be used provided they meet all other requirements of this Division. Qualification of a welding procedure by one Manufacturer shall not qualify that procedure for any other Manufacturer except as otherwise provided in Section IX, QG-106.

Welding procedures qualified in accordance with the simultaneous procedure qualification rules of Section IX, QG-106.4 are permitted by this Division.

UW-29 TESTS OF WELDERS AND WELDING OPERATORS

(a) The welders and welding operators used in welding pressure parts and in joining load-carrying nonpressure parts (attachments) to pressure parts shall be qualified in accordance with Section IX.

(1) The qualification test for welding operators of machine welding equipment shall be performed on a separate test plate prior to the start of welding or on the first workpiece.

(2) When stud welding is used to attach load-carrying studs, a production stud weld test of each welder or welding operator shall be performed on a separate test plate or tube prior to the start of welding on each work shift. This weld test shall consist of five studs, welded and tested by the bend or torque stud weld testing procedure described in Section IX.

(b) The welders and welding operators used in welding non-pressure-bearing attachments, which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.), to pressure parts shall comply with the following:

(1) When the welding process is manual, machine, or semiautomatic, qualification in accordance with Section IX is required.

(2) When welding is done by any automatic welding process, performance qualification testing is not required.

(3) When stud welding is used, a production stud weld test, appropriate to the end use application requirements, shall be specified by the Manufacturer and carried out on a separate test plate or tube at the start of each shift.

(c) Each welder and welding operator shall be assigned an identifying number, letter, or symbol by the manufacturer which shall be used to identify the work of that welder or welding operator in accordance with UW-37(f).

(d) The Manufacturer shall maintain a record of the welders and welding operators showing the date and result of tests and the identification mark assigned to each. These records shall be maintained in accordance with Section IX.

(e) Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. A performance qualification test conducted by one Manufacturer shall not qualify a welder or welding operator to do work for any other Manufacturer except as provided in Section IX, QG-106.

UW-30 LOWEST PERMISSIBLE TEMPERATURES FOR WELDING

It is recommended that no welding of any kind be done when the temperature of the base metal is lower than 0°F (−20°C). At temperatures between 32°F (0°C) and 0°F (−20°C), the surface of all areas within 3 in. (75 mm) of the point where a weld is to be started should be heated to a temperature at least warm to the hand [estimated to be above 60°F (15°C)] before welding is started. It is recommended also that no welding be done when surfaces are wet or covered with ice, when snow is falling on the surfaces to be welded, or during periods of high wind, unless the welders or welding operators and the work are properly protected.

UW-31 CUTTING, FITTING, AND ALIGNMENT

(a) When plates are shaped by oxygen or arc cutting, the edges to be welded shall be uniform and smooth and shall be freed of all loose scale and slag accumulations before welding (see UG-76 and UCS-5).

(b) Plates that are being welded shall be fitted, aligned, and retained in position during the welding operation.

(c) Bars, jacks, clamps, tack welds, or other appropriate means may be used to hold the edges of parts in alignment. Tack welds used to secure alignment shall either be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds, whether removed or left in place, shall be made using a fillet weld or butt weld procedure qualified in accordance with Section IX. Tack welds to be left in place shall be made by welders qualified in accordance with Section IX, and shall be examined visually for defects, and if found to be defective shall be removed.

Provided that the work is done under the provisions of U-2(b), it is not necessary that a subcontractor making such tack welds for a vessel or parts manufacturer be a holder of a Code Certificate of Authorization. The requirements of UW-26(d) do not apply to such tack welds.

(d) The edges of butt joints shall be held during welding so that the tolerances of UW-33 are not exceeded in the completed joint. When fitted girth joints have deviations exceeding the permitted tolerances, the head or shell ring, whichever is out-of-true, shall be reformed until the errors are within the limits specified. Where fillet welds are used, the lapped plates shall fit closely and be kept in contact during welding.

(e) When joining two parts by the inertia and continuous drive friction welding processes, one of the two parts must be held in a fixed position and the other part rotated. The two faces to be joined must be essentially symmetrical with respect to the axis of rotation. Some of the basic types of applicable joints are solid round to solid round, tube to tube, solid round to tube, solid round to plate, and tube to plate.

UW-32 CLEANING OF SURFACES TO BE WELDED

(a) The surfaces to be welded shall be clean and free of scale, rust, oil, grease, slag, detrimental oxides, and other deleterious foreign material. The method and extent of cleaning should be determined based on the material to be welded and the contaminants to be removed. When weld metal is to be deposited over a previously welded

surface, all slag shall be removed by a roughing tool, chisel, chipping hammer, or other suitable means so as to prevent inclusion of impurities in the weld metal.

(b) Cast surfaces to be welded shall be machined, chipped, or ground to remove foundry scale and to expose sound metal.

(c) The requirements in (a) and (b) above are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and by which the weld remains free from defects.

UW-33 ALIGNMENT TOLERANCE

(a) Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than the applicable amount for the welded joint category (see UW-3) under consideration, as listed in Table UW-33. The section thickness t is the nominal thickness of the thinner section at the joint.

(b) Any offset within the allowable tolerance provided above shall be faired at a three to one taper over the width of the finished weld, or if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. Such additional weld metal buildup shall be subject to the requirements of UW-42.

(25) UW-34 SPIN-HOLES

Spin-holes are permitted within heads or segments thereof to facilitate forming. Spin-holes not exceeding the size limitations of UG-36(c)(3)(-a) may be closed with a full-penetration weld using either a welded plug or weld metal. The weld and plug shall be no thinner than the head material adjacent to the spin-hole.

(25)

Table UW-33
Maximum Allowable Offset in Welded Joints

U.S. Customary Units		
	Joint Category	
Section Thickness, in.	**A**	**B, C, and D**
Up to $^1/_2$, incl.	$^1/_4t$	$^1/_4t$
Over $^1/_2$ to $^3/_4$, incl.	$^1/_8$ in.	$^1/_4t$
Over $^3/_4$ to $1^1/_2$, incl.	$^1/_8$ in.	$^3/_{16}$ in.
Over $1^1/_2$ to 2, incl.	$^1/_8$ in.	$^1/_8t$
Over 2	Lesser of $^1/_{16}t$ or $^3/_8$ in.	Lesser of $^1/_8t$ or $^3/_4$ in.
SI Units		
	Joint Category	
Section Thickness, mm	**A**	**B, C, and D**
Up to 13, incl.	$^1/_4t$	$^1/_4t$
Over 13 to 19, incl.	3 mm	$^1/_4t$
Over 19 to 38, incl.	3 mm	5 mm
Over 38 to 51, incl.	3 mm	$^1/_8t$
Over 51	Lesser of $^1/_{16}t$ or 10 mm	Lesser of $^1/_8t$ or 19 mm

These welds shall be examined in accordance with the specific NDE requirements of a Category D butt weld. These welds shall not be considered in establishing the joint efficiency of any part of the head or of the head-to-shell weld.

UW-35 COMPLETED GROOVE AND FILLET WELDS (25)

(a) Groove-welded butt, angle, and corner joints shall achieve complete joint penetration and complete fusion. Fillet welds shall achieve complete fusion into the base metal including the root of the joint but not necessarily beyond.

(b) As-welded surfaces are permitted. However, the welded surface shall be sufficiently free from coarse ripples, grooves, overlaps, and abrupt ridges and valleys that could impair proper interpretation of any required nondestructive examinations.

If an indication on a radiograph is suspected to be due to the surface condition of the weld, the radiograph shall be compared to the actual weld surface to aid in interpretation.

(c) A reduction in base metal thickness due to the welding process, including undercut, is acceptable provided the remaining base metal thickness is not

(1) less than the design thickness at any point

(2) reduced by more than the lesser of $^1/_{32}$ in. (0.8 mm) or 10% of the nominal thickness[47]

(d) Weld metal may be added as reinforcement to the face and root surface of the weld to ensure the weld surface does not fall below the base metal[48] surface.

(e) When a single-welded groove weld is made by using a backing strip that remains in place (Type No. 2 of Table UW 12), reinforcement requirements apply only to the weld face. The weld reinforcement thickness on each face shall not exceed the values shown in Table UW-35-1.

UW-36 FILLET WELDS (25)

DELETED

UW-37 MISCELLANEOUS WELDING REQUIREMENTS (25)

(a) The reverse side of double-welded joints shall be prepared by chipping, grinding, or melting out, so as to secure sound metal at the base of weld metal first deposited, before applying weld metal from the reverse side.

(b) The requirements in (a) above are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and by which the base of the weld remains free from defects.

(25)

Table UW-35-1 Maximum Reinforcement for Welded Joints

U.S. Customary Units

Material Nominal Thickness, in.	Maximum Reinforcement, in. — Category B and C Butt Welds	Maximum Reinforcement, in. — Other Welds
Less than $^3/_{32}$	$^3/_{32}$	$^1/_{32}$
$^3/_{32}$ to $^3/_{16}$, incl.	$^1/_8$	$^1/_{16}$
Over $^3/_{16}$ to $^1/_2$, incl.	$^5/_{32}$	$^3/_{32}$
Over $^1/_2$ to 1, incl.	$^3/_{16}$	$^3/_{32}$
Over 1 to 2, incl.	$^1/_4$	$^1/_8$
Over 2 to 3, incl.	$^1/_4$	$^5/_{32}$
Over 3 to 4, incl.	$^1/_4$	$^7/_{32}$
Over 4 to 5, incl.	$^1/_4$	$^1/_4$
Over 5	$^5/_{16}$	$^5/_{16}$

SI Units

Material Nominal Thickness, mm	Maximum Reinforcement, mm — Category B and C Butt Welds	Maximum Reinforcement, mm — Other Welds
Less than 2.4	2.5	0.8
2.4 to 4.8, incl.	3	1.5
Over 4.8 to 13, incl.	4	2.5
Over 13 to 25, incl.	5	2.5
Over 25 to 51, incl.	6	3
Over 51 to 76, incl.	6	4
Over 76 to 102, incl.	6	5.5
Over 102 to 127, incl.	6	6
Over 127	8	8

(c) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(d) Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

(e) In welding plug welds, a fillet around the bottom of the hole shall be deposited first.

(f) *Welder and Welding Operator Identification*

(1) Each welder and welding operator shall stamp the identifying number, letter, or symbol assigned by the Manufacturer, on or adjacent to and at intervals of not more than 3 ft (1 m) along the welds which they make in steel plates $^1/_4$ in. (6 mm) and over in thickness and in nonferrous plates $^1/_2$ in. (13 mm) and over in thickness; or a record shall be kept by the Manufacturer of welders and welding operators employed on each joint which shall be available to the Inspector. For identifying welds on vessels in which the wall thickness is less than $^1/_4$ in. (6 mm) for steel material and less than $^1/_2$ in. (13 mm) for nonferrous material, suitable stencil or other surface markings shall be used; or a record shall be kept by the Manufacturer of welders and welding operators employed on each joint which shall be available to the Inspector; or a stamp may be used provided the vessel part is not deformed and the following additional requirements are met:

(-a) for ferrous materials:

(-1) the materials shall be limited to P-No. 1 Gr. Nos. 1 and 2;

(-2) the minimum nominal plate thickness shall be $^3/_{16}$ in. (5 mm), or the minimum nominal pipe wall thickness shall be 0.154 in. (3.91 mm);

(-3) the minimum design metal temperature shall be no colder than −20°F (−29°C);

(-b) for nonferrous materials:

(-1) the materials shall be limited to aluminum as follows: SB-209 Alloys 3003, 5083, 5454, and 6061; SB-241 Alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 Alloys 3003, 5083, and 6061;

(-2) the minimum nominal plate thickness shall be 0.249 in. (6.32 mm), or the minimum nominal pipe thickness shall be 0.133 in. (3.37 mm).

(2) When a multiple number of permanent nonpressure part load bearing attachment welds, nonload-bearing welds such as stud welds, or special welds such as tube-to-tubesheet welds are made on a vessel, the Manufacturer need not identify the welder or welding operator that welded each individual joint provided:

(-a) the Manufacturer's Quality Control System includes a procedure that will identify the welders or welding operators that made such welds on each vessel so that the Inspector can verify that the welders or welding operators were all properly qualified;

(-b) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(3) Permanent identification of welders or welding operators making tack welds that become part of the final pressure weld is not required provided the Manufacturer's Quality Control System includes a procedure to permit the Inspector to verify that such tack welds were made by qualified welders or welding operators.

(g) The welded joint between two members joined by the inertia and continuous drive friction welding processes shall be a full penetration weld. Visual examination of the as-welded flash roll of each weld shall be made as an in-process check. The weld upset shall meet the specified amount within ±10%. The flash shall be removed to sound metal.

(h) Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments without postweld heat treatment, provided the following requirements are met:

(1) A Welding Procedure Specification shall be prepared in accordance with Section IX, insofar as possible describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application. Qualification of the welding procedure is not required.

(2) The energy output shall be limited to 125 W-sec.

(25) ## UW-38 REPAIR OF WELD DEFECTS

Defects, such as cracks, pinholes, and incomplete fusion, detected visually or by the hydrostatic or pneumatic test or by the examinations prescribed in UW-11 shall be removed by mechanical means or by thermal gouging processes, after which the joint shall be rewelded (see UW-40.5).

UW-39 PEENING

(a) Weld metal and heat-affected zones may be peened by manual, electric, or pneumatic means when it is deemed necessary or helpful to control distortion, to relieve residual stresses, or to improve the quality of the weld. Peening shall not be used on the initial (root) layer of weld metal nor on the final (face) layer unless the weld is subsequently postweld heat treated. In no case, however, is peening to be performed in lieu of any postweld heat treatment required by these rules.

(b) Controlled shot peening and other similar methods which are intended only to enhance surface properties of the vessel or vessel parts shall be performed after any nondestructive examinations and pressure tests required by these rules.

(25) ## UW-40 PROCEDURES FOR POSTWELD HEAT TREATMENT

UW-40.1 Introduction. Postweld heat treatment (PWHT) shall be performed following one of the procedures described in UW-40.3 in accordance with the requirements of the applicable Parts in Subsections C and D. For additional detailed recommendations regarding implementation and performance of these procedures, refer to Welding Research Council (WRC) Bulletin 452, June 2000, "Recommended Practices for Local Heating of Welds in Pressure Vessels."

UW-40.2 Definition.

soak band: the volume of metal that is required to be held at or above the minimum PWHT holding temperatures listed in the applicable Part of Subsection C. As a minimum, the soak band shall contain the weld, heat-affected zone, and a portion of base metal adjacent to the weld subject to heat treatment. The minimum width of the soak band shall be the lesser of the width of the weld plus 1t or 2 in. (50 mm) on each side or end of the weld, where t = nominal thickness (see UW-40.6).

UW-40.3 Treatment Procedures.

UW-40.3.1 Heating the Entire Vessel in an Enclosed Furnace. The preferred PWHT procedure is to heat the entire vessel in an enclosed furnace.

UW-40.3.2 Heating Oversized Vessels or Parts. When heating a vessel or part in separate sections, the following requirements shall be met:

(a) The portion outside of the furnace shall be protected from harmful thermal gradients.

(b) The cross section where the vessel projects from the furnace shall not intersect a nozzle or other structural discontinuity.

(c) There shall be an overlap of at least 5 ft (1.5 m) of the vessel sections receiving PWHT.

UW-40.3.3 Heating of Shell Sections or Portions of Vessels. Longitudinal joints or complicated welded details within vessel portions or shell sections may be subjected to a PWHT separately before joining them to make the completed vessel. Welds joining these sections in the completed vessel shall receive PWHT in accordance with UW-40.3.4 through UW-40.3.8 when required by this Division.

UW-40.3.4 Heating the Vessel Internally. Vessels may be heated internally by any suitable means that will ensure adequate temperature control and uniformity. Temperature indicating and recording devices shall be used to monitor and control the heat treatment to maintain a uniform temperature distribution in the vessel wall.

(a) Before heating, the vessel should be fully enclosed with insulating material, or the intended permanent insulation may be installed if it is suitable for the required temperature.

(b) The internal pressure in the vessel should be minimized while heating, but shall not exceed 50% of the maximum allowable working pressure for the highest metal temperature expected during the PWHT.

(c) The heating method shall avoid direct flame impingement on the vessel.

UW-40.3.5 Heating a Circumferential Band. Circumferential weld joints not previously subjected to PWHT, nozzles or other welded attachments that require PWHT added to a new vessel, or areas within new vessels or components receiving welded repairs may be subjected to a local PWHT as follows:

(a) The joints shall be heated by any suitable means that will ensure adequate temperature control and uniformity.

(b) The soak band shall extend around the full circumference with a uniform width that includes the elements requiring PWHT.

(c) The portion outside the soak band shall be protected from harmful thermal gradients throughout the heating and cooling cycle.

(d) The circumferential soak band shall be heated to the specified temperature and held for the required time.

UW-40.3.5.1 Alternate Method 1. The circumferential soak band may have a varied width in areas away from the nozzle or attachment weld requiring PWHT, provided the entire soak band is heated to the specified temperature and held for the required time.

UW-40.3.5.2 Alternate Method 2. The circumferential soak band may have a constant width around the entire vessel or component where both the following conditions are met:

(a) The required soak band away from the nozzle or welded attachment requiring PWHT is heated to a lower temperature than the required temperature.

(b) The required soak band away from the nozzle or welded attachment requiring PWHT and areas outside of the soak band are protected from harmful thermal gradients throughout the heating and cooling cycle.

UW-40.3.6 Heating Circumferential Joints of Pipe or Tubing.

(a) Circumferential joints in pipe or tubing shall be treated within a soak band that extends around the entire circumference.

(b) The portion outside the soak band shall be protected from harmful thermal gradients.

(c) The designer shall consider the effect of thermal restraint for a circumferential joint in the pipe or tube that is close to the vessel shell. Options include the following:

(1) providing an adequate distance between the circumferential joint and the vessel shell to prevent harmful thermal gradients at the nozzle attachment

(2) heating a full circumferential band around the shell, including the nozzle

UW-40.3.7 Heating Local Area Around Nozzles or Welded Attachments. When applying PWHT to nozzles or welded attachments located in larger radius sections of a double curvature head or a spherical shell or head, a circular soak band may be applied as follows:

(a) The soak band shall include the nozzle or welded attachment.

(b) The soak band shall be heated uniformly to the specified temperature and held for the required time.

(c) The portion of the vessel outside of the soak band shall be protected from harmful thermal gradients.

UW-40.3.8 Heating of Other Configurations. Local area heating of other configurations, such as "spots" or "bull's-eye" local heating not addressed in UW-40.3.1 through UW-40.3.7, is permitted under the following conditions:

(a) The PWHT procedure shall be based on documented experience or evaluation of sufficiently similar conditions.

(b) The PWHT procedure shall address all the following:

(1) the effects of thermal gradients within the heated area

(2) all significant structural discontinuities, such as nozzles, attachments, and head-to-shell junctures

(3) any mechanical loads which may be present during PWHT

(4) protection from harmful thermal gradients in the portions of the vessel or component outside the soak band

UW-40.4 Application of Heat Treatment.

UW-40.4.1 Holding Temperatures and Heating and Cooling Rates. The minimum holding temperatures and the rates of heating and cooling to be used when PWHT is required for vessels and components are given in UCS-56, UHT-56, UNF-56, and UHA-32.

UW-40.4.2 Thermocouple Placement. When multiple pressure vessels or vessel parts are to be heated in one furnace charge, thermocouples shall be placed where potential temperature variations are anticipated to indicate the true[49] temperature for all components being heated.

UW-40.4.3 PWHT of Dissimilar Materials. Some PWHT holding temperatures may have harmful effects on the properties of dissimilar materials.

(a) When pressure parts of different P-Numbers are joined by welding, engineering judgment shall be applied to the selection of the holding temperature and holding time to ensure the resulting material properties are suitable for the intended service.

(b) As an alternative, a welding procedure qualified in accordance with the buttering rules of Section IX, QW-283 may be used.

UW-40.5 Sequencing of PWHT. When PWHT is required, it shall be applied prior to the final pressure test and after any welded repairs except as otherwise permitted by UCS-56.7. A preliminary pressure test may be performed prior to applying PWHT to reveal any leaks that may require repairs.

UW-40.6 Nominal Thickness for Determining PWHT Requirements. The term "nominal thickness" as used in Tables UCS-56-1 through UCS-56-12, UHA-32-1 through UHA-32-7, and UHT-56 is the thickness of the welded joint as defined in (a) through (c) below.

(a) When pressure vessels or parts are simultaneously subjected to PWHT, the nominal thickness is the greatest value defined in UW-40.6.1 through UW-40.6.7 for all weld types in any vessel or part that has not been postweld heat treated.

(b) The thickness of the head, shell, nozzle neck, or other parts as used in UW-40.6.1 through UW-40.6.7 shall be the wall thickness of the part at the welded joint under consideration.

(c) For plate material, at the Manufacturer's option, the thickness shown on the Material Test Report or certificate of compliance before forming may be used in lieu of measuring the actual thickness at the welded joint.

UW-40.6.1 Butt Joints. When a full-penetration butt joint connects parts of the same thickness, the nominal thickness is the total depth of the weld exclusive of any permitted weld reinforcement.

UW-40.6.2 Groove Welds. For single- or double-sided groove welds, the nominal thickness is the total depth of the groove.

UW-40.6.3 Fillet Welds. For fillet welds, the nominal thickness is the theoretical throat.

UW-40.6.4 Fillet and Groove Welds. If a fillet weld is used in combination with a groove weld, the nominal thickness is the greater of the groove depth or the theoretical throat.

UW-40.6.5 Stud Welds. The nominal thickness shall be the diameter of the stud.

UW-40.6.6 Welds of Unequal Thickness. When a welded joint connects parts of unequal thicknesses, the nominal thickness shall be the following:

(a) the thinner of the two members in a butt joint, including head-to-shell connections

(b) the greater of the shell thickness or the theoretical fillet weld throat in connections to intermediate heads of the type shown in Figure UW-13.1, sketch (e)

(c) the thickness of the shell in connections to tubesheets, flat heads, covers, flanges (except for welded parts depicted in Mandatory Appendix 2, Figure 2-4, sketch (7), where the thickness of the weld shall govern), or similar constructions

(d) in Figures UW-16.1 and UW-16.2, the greater of the weld thickness across the nozzle neck, shell, head, reinforcing pad, or attachment fillet weld

(e) the thickness of the nozzle neck at the joint connecting a nozzle to a flange

(f) the thickness of the weld at the point of attachment when a nonpressure part is welded to a pressure part

(g) the thickness of the tube in tube-to-tubesheet connections

(h) the thickness of the weld metal overlay when weld metal overlay is the only welding applied

UW-40.6.7 Repair Welds. For repairs, the nominal thickness is the depth of the repair weld.

UW-41 SECTIONING OF WELDED JOINTS

Welded joints may be examined by sectioning when agreed to by user and Manufacturer, but this examination shall not be considered a substitute for spot radiographic examination. This type of examination has no effect on the joint factors in Table UW-12. The method of closing the hole by welding is subject to acceptance by the Inspector. Some acceptable methods are given in Nonmandatory Appendix K.

UW-42 SURFACE WELD METAL BUILDUP

(a) Construction in which deposits of weld metal are applied to the surface of base metal for the purpose of restoring the thickness of the base metal for strength consideration; or modifying the configuration of weld joints in order to provide the tapered transition requirements of UW-9(c) and UW-33(b) shall be performed in accordance with the rules in (b) and (c).

(b) Procedure Qualification. A groove welding procedure qualification in accordance with provisions of Section IX shall be performed for the thickness of weld metal deposited, prior to production welding.

(c) Examination Requirements

(1) All weld metal buildup shall be examined over the full surface of the deposit by either magnetic particle examination to the requirements of Mandatory Appendix 6, or by liquid penetrant examination to the requirements of Mandatory Appendix 8.

(2) When such surface weld metal buildup is used in welded joints which require full or spot radiographic examination, the weld metal buildup shall be included in the examination.

INSPECTION AND TESTS

UW-46 GENERAL (25)

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsections C and D. [For tests on reinforcing plates, see UG-37(g).]

UW-47 CHECK OF WELDING PROCEDURE (25)

The Inspector shall verify that the welding procedure employed in the construction of a vessel has been qualified under the provisions of Section IX. The Manufacturer shall submit evidence to the Inspector that the requirements have been met.

UW-48 CHECK OF WELDER AND WELDING OPERATOR QUALIFICATIONS (25)

(a) The Manufacturer shall certify that the welding on a vessel has been done only by welders and welding operators who have been qualified under the requirements of Section IX and the Inspector shall verify that only qualified welders and welding operators have been used.

(b) The Manufacturer shall make available to the Inspector the record of the qualification tests of each welder and welding operator. The Inspector shall have the right at any time to call for and witness tests of the welding procedure or of the ability of any welder and welding operator.

UW-49 CHECK OF POSTWELD HEAT TREATMENT PRACTICE (25)

The Inspector shall verify that all postweld heat treatment has been correctly performed and that the temperature readings conform to the requirements.

(25) UW-50 NONDESTRUCTIVE EXAMINATION OF WELDS ON VESSELS TO BE PNEUMATICALLY TESTED

(a) On welded pressure vessels to be pneumatically tested in accordance with UG-100, the following shall be examined before the pneumatic test is performed, for the purpose of detecting cracks. Examination shall be by the magnetic particle or liquid penetrant method when the material is ferromagnetic or by the liquid penetrant method when the material is nonferromagnetic.

(1) the full length of all welds around openings, accessible to surface NDE

(2) the full length of all attachment welds having a throat thickness greater than $^1/_4$ in. (6 mm), including welds attaching nonpressure parts to pressure parts, accessible to surface NDE

(3) any area where welds having a throat thickness exceeding $^1/_4$ in. (6 mm) have been removed

(b) The weld joint examination requirements given in (a) may be waived when the maximum allowable working pressure of the vessel is no greater than 500 psi (3.5 MPa) and the following applicable requirement is met:

(1) For Part UCS materials, the governing thickness as defined in UCS-66(a) shall be limited to a maximum governing thickness of $^1/_2$ in. (13 mm) for materials assigned to Curve A, and 1 in. (25 mm) for materials assigned to Curve B, C, or D in Figure UCS-66 (Figure UCS-66M).

(2) For austenitic chromium–nickel stainless steels 304, 304L, 316, 316L, 321, and 347 in Part UHA, the maximum nominal material thickness shall be $^3/_4$ in. (19 mm).

(3) For aluminum, aluminum alloy 3000 series, aluminum alloy 5000 series, and aluminum alloy 6061-T6 in Part UNF, the maximum nominal material thickness shall be 1 in. (25 mm).

(25) UW-51 RADIOGRAPHIC EXAMINATION OF WELDED JOINTS

(a) All welded joints to be radiographed shall be examined in accordance with Section V, Article 2, except as specified below.

(1) A complete set of radiographic images and radiograph review forms, as described in Section V, Article 2, for each vessel or vessel part shall be retained by the Manufacturer, as follows:

(-a) radiographic images until the radiograph review form has been accepted by the Inspector. Deterioration of radiographic film is not a violation of the requirement for the maintenance of the records.

(-b) radiograph review forms as required by Mandatory Appendix 10, 10-13.

(2) Demonstration of acceptable density on radiographic films and the ability to see the prescribed image quality indicator (IQI) image and the specified hole or the designated wire of a wire IQI shall be considered satisfactory evidence of compliance with Section V, Article 2.

(3) The requirements of Section V, Article 2, T-274.2, are to be used only as a guide for film-based radiography.

(4) As an alternative to the radiographic examination requirements above, all welds in which the thinner of the members joined is $^1/_4$ in. (6 mm) thick and greater may be examined using the ultrasonic (UT) method specified by UW-53(b) or UW-53(c).

(b) Indications revealed by radiography within a weld that exceed the following criteria are unacceptable and therefore are defects:

(1) any indication characterized as a crack or zone of incomplete fusion or penetration;

(2) any other elongated indication on the radiograph which has length greater than:

(-a) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm)

(-b) $^1/_3 t$ for t from $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm)

(-c) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm)

where

t = the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

(3) any group of aligned indications that have an aggregate length greater than t in a length of $12t$, except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group;

(4) rounded indications in excess of that specified by the acceptance standards given in Mandatory Appendix 4.

If an indication on a radiograph is suspected to be due to the surface condition of the weld, the radiograph shall be compared to the actual weld surface to aid in interpretation.

Defects shall be repaired as provided in UW-38, and the repaired area shall be reexamined. In lieu of reexamination by radiography, the repaired weld may be ultrasonically examined in accordance with Mandatory Appendix 12 at the Manufacturer's option. For material thicknesses in excess of 1 in. (25 mm), the concurrence of the user shall be obtained. This ultrasonic examination shall be noted under "Remarks" on the Manufacturer's Data Report Form.

UW-52 SPOT EXAMINATION OF WELDED JOINTS (25)

NOTE: Spot radiographing of a welded joint is recognized as an effective inspection tool. The spot radiography rules are also considered to be an aid to quality control. Spot radiographs made directly after a welder or an operator has completed a unit of weld proves that the work is or is not being done in accordance with a satisfactory procedure. If the work is unsatisfactory, corrective steps can then be taken to improve the welding in the subsequent units, which unquestionably will improve the weld quality.

Spot radiography in accordance with these rules will not ensure a fabrication product of predetermined quality level throughout. It must be realized that an accepted vessel under these spot radiography rules may still contain defects which might be disclosed on further examination. If all radiographically disclosed weld defects must be eliminated from a vessel, then 100% radiography must be employed.

(a) Butt-welded joints that are to be spot radiographed shall be examined locally as provided herein.

(b) Minimum Extent of Spot Radiographic Examination

(1) One spot shall be examined on each vessel for each 50 ft (15 m) increment of weld or fraction thereof for which a joint efficiency from column (b) of Table UW-12 is selected. However, for identical vessels or parts, each with less than 50 ft (15 m) of weld for which a joint efficiency from column (b) of Table UW-12 is selected, 50 ft (15 m) increments of weld may be represented by one spot examination.

(2) For each increment of weld to be examined, a sufficient number of spot radiographs shall be taken to examine the welding of each welder or welding operator. Under conditions where two or more welders or welding operators make weld layers in a joint, or on the two sides of a double-welded butt joint, one spot may represent the work of all welders or welding operators.

(3) Each spot examination shall be made as soon as practicable after completion of the increment of weld to be examined. The location of the spot shall be chosen by the Inspector after completion of the increment of welding to be examined, except that when the Inspector has been notified in advance and cannot be present or otherwise make the selection, the Manufacturer may select the spots.

(4) Radiographs required at specific locations to satisfy the rules of other paragraphs, such as UW-9(d), UW-11(a)(5)(-b), and UW-14.2, shall not be used to satisfy the requirements for spot radiography.

(c) Standards for Spot Radiographic Examination. Spot examination by radiography shall be made in accordance with the technique prescribed in UW-51(a). The minimum length of spot radiograph shall be 6 in. (150 mm). Spot radiographs may be retained or be discarded by the Manufacturer after acceptance of the vessel by the Inspector. The acceptability of welds examined by spot radiography shall be judged by the following standards:

(1) Welds in which indications are characterized as cracks or zones of incomplete fusion or penetration shall be unacceptable.

(2) Welds having indications characterized as slag inclusions or cavities are unacceptable when the indication length exceeds $^2/_3t$, where t is defined as shown in UW-51(b)(2). For all thicknesses, indications less than $^1/_4$ in. (6 mm) are acceptable, and indications greater than $^3/_4$ in. (19 mm) are unacceptable. Multiple aligned indications meeting these acceptance criteria are acceptable when the sum of their longest dimensions indications does not exceed t within a length of $6t$ (or proportionally for radiographs shorter than $6t$), and when the longest length L for each indication is separated by a distance not less than $3L$ from adjacent indications.

(3) Rounded indications are not a factor in the acceptability of welds not required to be fully radiographed.

(d) Evaluation and Retests

(1) When a spot, radiographed as required in (b)(1) or (b)(2) above, is acceptable in accordance with (c)(1) and (c)(2) above, the entire weld increment represented by this radiograph is acceptable.

(2) When a spot, radiographed as required in (b)(1) or (b)(2) above, has been examined and the radiograph discloses welding which does not comply with the minimum quality requirements of (c)(1) or (c)(2) above, two additional spots shall be radiographically examined in the same weld increment at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or fabricator as provided for the original spot examination in (b)(3) above.

(-a) If the two additional spots examined show welding which meets the minimum quality requirements of (c)(1) and (c)(2) above, the entire weld increment represented by the three radiographs is acceptable provided the defects disclosed by the first of the three radiographs are removed and the area repaired by welding. The weld repaired area shall be radiographically examined in accordance with the foregoing requirements of UW-52.

(-b) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of (c)(1) or (c)(2) above, the entire increment of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the fabricator's option, the entire increment of weld represented shall be completely radiographed and only defects need be corrected.

(-c) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint, or the weld repaired areas, shall be spot radiographically examined at one location in accordance with the foregoing requirements of UW-52.

UW-53 ULTRASONIC EXAMINATION OF WELDED JOINTS

(a) Ultrasonic examination of welded joints whose joint efficiency is not determined by ultrasonic examinations may be performed and evaluated in accordance with Mandatory Appendix 12.

(b) Ultrasonic examination of welds per UW-51(a)(4) shall be performed and evaluated in accordance with the requirements of Section VIII, Division 2, 7.5.5.

(c) Phased array manual raster ultrasonic examinations may be used to establish the joint efficiency of the final closure seam of a pressure vessel whose construction, geometric configuration, or accessibility prohibits obtaining interpretable radiographs in accordance with UW-51(a) and the ultrasonic examination requirements of (b) when all of the following conditions are met:

(1) The absence of suitable radiographic or ultrasonic examination equipment shall not be considered acceptable justification for using these provisions.

(2) The examination shall be performed in accordance with a written procedure conforming to the requirements of Section V, Article 4, Mandatory Appendices IV and V, applying phased array manual raster ultrasonic examination techniques with a linear array.

(3) The examination procedure shall be qualified as set forth in Section V, Article 1, T-150(d) and Section V, Article 4, Mandatory Appendix IX.

(4) Contractor qualification records of certified personnel shall be reviewed and approved by the Manufacturer and maintained by their employer.

(5) Only qualified UT personnel trained in the use of the equipment who have either participated in the procedure qualification or have successfully passed a performance demonstration as set forth in Section V, Article 1, T-150(a) shall conduct production scans.

(6) The examination shall employ a scanner having data acquisition, encoding, and analysis abilities.

(7) An initial straight beam material examination for reflectors that could interfere with the angle beam examination shall be performed manually (see Section V, Article 4, T-472).

(8) For material thickness greater than 8 in. (200 mm), the area to be examined shall include the volume of the weld plus 2 in. (50 mm) on each side of the weld.

(9) For material thickness 8 in. (200 mm) or less, the area to be examined shall include the volume of the weld plus the lesser of 1 in. (25 mm) or t on each side of the weld. Alternatively, the area to be examined may be reduced to include the actual heat-affected zone (HAZ) plus $^1/_4$ in. (6 mm) of base material beyond the heat-affected zone on each side of the weld, provided the following requirements are met:

(-a) The extent of the weld HAZ is measured and documented during the weld qualification process.

(-b) The ultrasonic transducer positioning is controlled using a reference mark (paint or low-stress stamp adjacent to the weld) or other means that ensure that the actual HAZ plus an additional $^1/_4$ in. (6 mm) of base metal is examined.

(10) Calibration of the examination system shall be performed in accordance with the applicable requirements of Section V, Article 4, T-460.

(11) Flaw sizing shall be in accordance with Section VIII, Division 2, 7.5.5.2.

(12) Flaw evaluation and acceptance shall be in accordance with Section VIII, Division 2, 7.5.5.3.

A maximum weld joint efficiency of E = 1.0 may be assigned to final closure seams that are found to be acceptable following these examination rules. An entry shall be included in the "Remarks" section of the Manufacturer's Data Report that states "Ultrasonic examination of the vessel closure seam was performed under the rules of (c).

UW-54 QUALIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

Personnel performing nondestructive examinations in accordance with UW-51, UW-52, or UW-53 shall be qualified and certified in accordance with the requirements of Section V, Article 1, T-120(e), T-120(f), T-120(g), T-120(i), T-120(j), or T-120(k), as applicable.

UW-55 DIFFUSION WELDING EXAMINATION (25)

Liquid penetrant examination shall be performed on the plate edges of the diffusion-welded plate pack in accordance with Mandatory Appendix 8.

(a) When machining of the plate edges is performed, the examination shall be performed after machining.

(b) Diffusion-welded joints shall be exempt from liquid penetrant examination in areas where channels are open to the surface of the diffusion-welded plate pack. This exclusion also includes a border around the open channel area smaller than 5 times the channel height.

MARKING AND REPORTS

UW-60 GENERAL

The provisions for marking and reports, UG-115 through UG-120, shall apply without supplement to welded pressure vessels.

PART UF
REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY FORGING

GENERAL

(25) UF-1 SCOPE

The rules in Part UF are applicable to forged pressure vessels without longitudinal joints, including their component parts that are fabricated of carbon and low alloy steels or of high alloy steels within the limitations of Part UHA. These rules shall be used in conjunction with the applicable requirements in Subsection A, and with the specific requirements in Subsections C and D.

MATERIALS

(25) UF-5 GENERAL

(a) Materials used in the construction of forged pressure vessels shall comply with the requirements for materials given in UG-4 through UG-14, except as specifically limited or extended in (b) and (c) below, and in UF-6.

(b) The heat analysis of forgings to be fabricated by welding shall not exceed carbon 0.35%. However, when the welding involves only minor nonpressure attachments as limited in UF-32, seal welding of threaded connections as permitted in UF-43, or repairs as limited by UF-37, the carbon content shall not exceed 0.50% by heat analysis. When by heat analysis the carbon analysis exceeds 0.50% no welding is permitted.

(c) SA-372 materials that are subjected to liquid quench and temper heat treatment and that have a specified minimum tensile strength exceeding 95 ksi (655 MPa) may be subjected to accelerated cooling or may be quenched and tempered to attain their specified minimum properties provided

(1) after heat treatment, inspection for injurious defects shall be performed according to UF-31(b)(1);

(2) tensile strength shall not be greater than 20,000 psi (140 MPa) above their specified minimum tensile strength.

(d) For vessels constructed of SA-372 Grade J, Class 110; Grade L; Grade N, Class 100 or 120; or Grade P, Class 100 or 120 material, transverse impact tests shall be made at the minimum allowable temperature in accordance with Part UHT, except in no case shall the test temperature be higher than −20°F (−29°C). Certification is required. An ultrasonic examination shall be made in accordance with UF-55.

UF-6 FORGINGS

All materials subject to stress due to pressure shall conform to one of the specifications given in Section II and limited to those listed in Tables UCS-23 and UHA-23 for forgings or to plates, and seamless pipe and tube when such material is further processed by a forging operation.

UF-7 FORGED STEEL ROLLS USED FOR CORRUGATING PAPER MACHINERY

Materials and rules of construction to be applied in the manufacture of forged steel corrugating and pressure rolls used in machinery for producing corrugated paper are covered in Section II, Part A, SA-649.

DESIGN

UF-12 GENERAL (25)

The rules in the following paragraphs apply specifically to vessels or main sections of vessels that are forged from ingots, slabs, billets, plate, pipe, or tubes, and shall be used to supplement the requirements for design which are applicable, as given in UG-16 through UG-55, and those given in UCS-16 through UCS-67, and UHA-20 through UHA-34. Sections of vessels may be joined by any method permitted in the several parts of this Division except as limited in UF-5(b) and UF-5(c).

Vessels constructed of SA-372 forging material must be of streamlined design, and stress raisers, such as abrupt changes in section, shall be minimized. Openings in vessels constructed of liquid quenched and tempered materials, other than austenitic steel, shall be reinforced in accordance with UG-37; UG-36(c)(3) shall not apply.

The nominal wall thickness of the cylindrical shell of vessels constructed of SA-372 Grade J, Class 110 shall not exceed 2 in. (50 mm).

UF-13 HEAD DESIGN

(a) The minimum required thickness of forged heads shall be computed using the equations of UG-32. When heads are made separate from the body forging they may be attached by any method permitted in the several parts of this Division except as limited in UF-5(b) and UF-5(c).

(b) The juncture of a forged conical head with the body shall be a knuckle, the inside radius of which shall be not less than 6% of the internal diameter of the vessel. The thickness at the knuckle shall be not less than that of the cylinder and shall be faired into that of the head at the base of the cone.

(c) Except for the $3t$ requirements in UG-32(i) the design of the head shall comply with the applicable provisions of UG-32, UG-33, UG-34, and 1-6.

UF-25 CORROSION ALLOWANCE

Provision shall be made for corrosion in accordance with the requirements in UG-25.

FABRICATION

UF-26 GENERAL

The rules in the following paragraphs supplement the applicable requirements for fabrication given in UG-75 through UG-84 and UCS-79. For high alloy steel forged vessels, the applicable paragraphs of Part UHA shall also apply.

UF-27 TOLERANCES ON BODY FORGINGS

(a) The inner surface of the body shall be true-to-round to the degree that the maximum difference between any two diameters at 90 deg to each other, determined for any critical cross section, does not exceed 1% of the mean diameter at that section. Chip marks and minor depressions in the inner surface may be filled by welding to meet these tolerances when the welding is done as permitted in UF-32.

(b) If out-of-roundness exceeds the limit in (a) and the condition cannot be corrected, the forging shall be rejected except that if the out-of-roundness does not exceed 3%, the forging may be certified for a lower pressure in the formula:

$$\text{Reduced pressure } P' = P\left(\frac{1.25}{\frac{S_b}{S}+1}\right)$$

and in which

$$S_b = \frac{1.5 P R_1 t (D_1 - D_2)}{t^3 + 3\frac{P}{E} R_1 R_a^2}$$

where

D_1, D_2 = the inside diameters maximum and minimum, respectively, as measured for the critical section, and for one additional section in each direction therefrom at a distance not exceeding $0.2D_2$. The average of the three readings for D_1 and D_2, respectively, shall be inserted in the formula.

E = modulus of elasticity of material at design temperature

P = maximum allowable working pressure for forging meeting the requirements of (a)

R_1 = average inside radius at critical section
= $\frac{1}{4}(D_1 + D_2)$

R_a = average radius to middle of shell wall at critical section
= $\frac{1}{4}(D_1 + D_2) + t/2$

S = design stress value, psi (kPa), at metal service temperature

S_b = bending stress at metal service temperature

t = the average (mean) thickness

NOTES:

(1) Use $P' = P$ when S_b is less than $0.25S$.

(2) In all measurements, correct for corrosion allowance if specified.

UF-28 METHODS OF FORMING FORGED HEADS

Forged heads shall be made either by closing in extensions of the body of such shape and dimensions as may be required to produce the final form desired, or by separate forgings [see UF-13(a)].

UF-29 TOLERANCE ON FORGED HEADS

Forged heads shall be as true as it is practicable to make them to the shape shown on the design drawings. Any deviations therefrom shall merge smoothly into the general shape of the head and shall not evidence a decrease of strength for the sections as required by the equations for design.

UF-30 LOCALIZED THIN AREAS

Forgings are permitted to have small areas thinner than required if the adjacent areas surrounding each have sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in UG-40.

UF-31 HEAT TREATMENT

(a) Normalized or Annealed Material

(1) After all forging is completed, each vessel or forged part fabricated without welding shall be heat treated in accordance with the applicable material specification. When defects are repaired by welding, subsequent heat treatment may be necessary in accordance with UF-37(b).

(2) Vessels fabricated by welding of forged parts requiring heat treatment shall be heat treated in accordance with the applicable material specification as follows:

(-a) after all welding is completed; or

(-b) prior to welding, followed by postweld heat treatment of the finished weld in accordance with UW-40;

(-c) when the welding involves only minor nonpressure attachments to vessels having carbon content exceeding 0.35% but not exceeding 0.50% by ladle analysis, requirements of UF-32(b) shall govern.

In the case of austenitic steels, the heat treatment procedures followed shall be in accordance with UHA-32.

(b) Liquid Quenched SA-372. Vessels fabricated from SA-372 forging material to be liquid quenched and tempered shall be subjected to this heat treatment in accordance with the applicable material specifications after the completion of all forging, welding of nonpressure attachments as permitted by UF-32, and repair welding as limited by UF-37. Seal welding of threaded connections, as permitted in UF-43, may be performed either before or after this heat treatment.

(1) After final heat treatment, such vessels shall be examined for the presence of cracks on the outside surface of the shell portion and on the inside surface where practicable. This examination shall be made by liquid penetrant when the material is nonferromagnetic and by liquid penetrant or magnetic particle examination when the material is ferromagnetic.

(2) After final heat treatment, liquid quenched and tempered vessels, except as provided in (3) below, shall be subjected to Brinell hardness tests in at least three different locations representing approximately the center and each end of the heat-treated shell. The tests shall meet the following requirements:

(-a) The distance between adjacent test locations shall be not more than 5 ft (1.5 m).

(-b) A minimum of four hardness readings shall be taken at each location.

(-c) The average of the four readings (HB_{ave}) at each location shall be calculated and the range of all average values shall not exceed 40 Brinell scale.

(-d) The specified minimum and maximum tensile strengths of SA-372 forging shall be converted to Brinell hardness values as HB_{min} and HB_{max}, respectively, in accordance with ASME SA-370. HB_{ave} values shall be not less than 90% of HB_{min} and not more than HB_{max}.

Other hardness testing methods, except superficial or micro hardness, may be used and converted to Brinell numbers in accordance with ASME SA-370. Reheat treatment is permitted if the hardness test results do not meet the above requirements

(3) For vessels which are integrally forged, having an overall length less than 5 ft (1.5 m) and a nominal thickness not exceeding $^1/_2$ in. (13 mm), the requirements of (2) above may be modified by taking a minimum of two hardness readings at each end of the vessel. These four hardness readings shall satisfy the requirements of (2) above as if the four hardnesses were applicable to one section.

(c) Non-Heat-Treated Material. Postweld heat treatment of vessels fabricated by welding of forged parts not requiring heat treatment shall meet with the requirements of UCS-56.

UF-32 WELDING FOR FABRICATION (25)

(a) All welding used in connection with the fabrication of forged vessels or components shall comply with the applicable requirements of Parts UW, UCS, and UHA and UF-5(b) except as modified in (b) and (c) below. Procedure qualification in accordance with Section IX shall be performed with the heat treatment condition of the base metal and weld metal as in UF-31 as contemplated for the actual work.

(b) When the carbon content of the material exceeds 0.35% by ladle analysis, the vessel or part shall be fabricated without welding of any kind, except for repairs [see UF-37(b)], for seal welding of threaded connections as permitted in UF-43, and for minor nonpressure attachments. Minor nonpressure attachments shall be joined by fillet welds of not over $^1/_4$ in. (6 mm) throat dimensions. Such welding shall be allowed under the following conditions:

(1) The suitability of the electrode and procedure shall be established by making a groove weld specimen as shown in Section IX, Figure QW-461.2 in material of the same analysis and of thickness in conformance with Section IX, QW-451. The specimen before welding shall be in the same condition of heat treatment as the work it represents, and after welding the specimen shall be subjected to heat treatment equivalent to that contemplated for the work. Tensile and bend tests, as shown in Section IX, Figures QW-462.1(a) through QW-462.1(e) and Figures QW-462.2 and QW-462.3(a), shall be made. These tests shall meet the requirements of Section IX, QW-150 and QW-160. The radius of the mandrel used in the guided bend test shall be as follows:

Specimen Thickness	Radius of Mandrel, *B* [Note (1)]	Radius of Die, *D* [Note (1)]
$^3/_8$ in. (10 mm)	$1^1/_2$ in. (38 mm)	$1^{11}/_{16}$ in. (42 mm)
t	$3^1/_3 t$	$4^1/_3 t$ + $^1/_{16}$ in. (1.5 mm)

NOTE:
(1) Corresponds to dimensions *B* and *D* in Section IX, Figure QW-466.1, and other dimensions to be in proportion.

Any cutting and gouging processes used in the repair work shall be included as part of the procedure qualification.

(2) Welders shall be qualified for fillet welding specified by making and testing a specimen in accordance with Section IX, QW-180 and Figure QW-462.4(b). Welders shall be qualified for repair welding by making a test plate in accordance with Section IX, Figure QW-461.3 from which the bend tests outlined in Section IX, QW-452 shall be made. The electrode used in making these tests shall be of the same classification number as that specified in the procedure. The material for these tests can be carbon steel plate or pipe provided the test specimens are preheated, welded and postheated in accordance with the procedure specification for the type of electrode involved.

(3) The finished weld shall be postweld heat treated or given a further heat treatment as required by the applicable material specification. The types of welding permitted in (b) shall be performed prior to final heat treatment except for seal welding of threaded openings which may be performed either before or after final heat treatment.

(4) The finished welds shall be examined after postweld heat treatment by liquid penetrant when the material is nonferromagnetic and by liquid penetrant or magnetic particle examination using the prod method when the material is ferromagnetic.

(c) The following requirements shall be used to qualify welding procedure and welder performance for seal welding of threaded connections in seamless forged pressure vessels of SA-372 Grades A, B, C, D, E, F, G, H, and J materials:

(1) The suitability of the welding procedure, including electrode, and the welder performance shall be established by making a seal weld in the welding position to be used for the actual work and in a full-size prototype of the vessel neck, including at least some portion of the integrally forged head, conforming to the requirements of UF-43 and the same geometry, thickness, vessel material type, threaded-plug material type, and heat treatment as that for the production vessel it represents.

(2) The seal weld in the prototype at the threaded connection of the neck and plug shall be cross sectioned to provide four macro-test specimens taken 90 deg apart.

(3) One face of each cross section shall be smoothed and etched with suitable etchant (see Section IX, QW-470) to give a clear definition of the weld metal and heat-affected zone. Visual examination of the cross sections of the weld metal and heat-affected zone shall show complete fusion and freedom from cracks.

(4) All production welding shall be done in accordance with the procedure qualification of (1) above, including the preheat and the electrode of the same classification as that specified in the procedure, and with welders qualified using that procedure.

(5) Seal welding of threaded connections may be performed either before or after final heat treatment.

(6) The finished weld shall be examined by liquid penetrant or magnetic particle examination using the prod method.

(d) Welding of SA-372 Grades N and P is prohibited.

(25) UF-37 REPAIR OF DEFECTS IN MATERIAL

(a) Surface defects, such as chip marks, blemishes, or other irregularities, shall be removed by grinding or machining and the surface exposed shall be blended smoothly into the adjacent area where sufficient wall thickness permits thin areas in compliance with the requirements of UF-30.

(b) Thinning to remove imperfections beyond those permitted in UF-30 may be repaired by welding only after acceptance by the Inspector. Defects shall be removed to sound metal as shown by acid etch or any other suitable method of examination. The welding shall be as outlined below.

(1) Material Having Carbon Content of 0.35% or Less (by Ladle Analysis)

(-a) The welding procedure and welders shall be qualified in accordance with Section IX.

(-b) Postweld heat treatment after welding shall be governed as follows.

(-1) All welding shall be postweld heat treated if UCS-56 requires postweld heat treatment, for all thicknesses of material of the analysis being used.

(-2) Fillet welds need not be postweld heat treated unless required by (-1) above or unless the fillet welds exceed the limits given in UCS-56.

(-3) Repair welding shall be postweld heat treated when required by (-1) above or if it exceeds 6 in.^{2} (4 000 mm^2) at any spot or if the maximum depth exceeds $^1/_4$ in. (6 mm).

(-c) Repair welding shall be radiographed if the maximum depth exceeds $^3/_8$ in. (10 mm). Repair welds $^3/_8$ in. (10 mm) and under in depth which exceed 6 in.^{2} (4 000 mm^2) at any spot and those made in materials requiring postweld heat treatment shall be examined by radiographing, magnetic particle or liquid penetrant examination, or any alternative method suitable for revealing cracks.

(-d) For liquid quenched and tempered steels, other than austenitic steels, welding repairs shall be in accordance with (3).

(2) Material Having Carbon Content Over 0.35% (by Ladle Analysis)

(-a) Welding repairs shall conform with UF-32(b) except that if the maximum weld depth exceeds $^1/_4$ in. (6 mm), radiography, in addition to magnetic particle or liquid penetrant examination, shall be used.

(-b) For liquid quenched and tempered steels, other than austenitic steel, welding repair shall be in accordance with (3) below.

(3) Welding repairs of materials which are to be or have been liquid quenched and tempered, regardless of depth or area of repairs, shall have the repaired area radiographed and examined by magnetic particle or liquid penetrant examination.

(4) Repair welding of SA-372 Grades N and P is prohibited.

UF-38 REPAIR OF WELD DEFECTS (25)

The repair of welds of forgings having carbon content not exceeding 0.35% by ladle analysis shall follow the requirements of UW-38. Welding of SA-372 Grades N and P is prohibited.

(25) UF-43 ATTACHMENT OF THREADED NOZZLES TO INTEGRALLY FORGED NECKS AND THICKENED HEADS ON VESSELS

Threaded openings, over NPS 3 (DN 80), but not exceeding the smaller of one-half of the vessel diameter or NPS 8 (DN 200), may be used in the heads of vessels having integrally forged heads and necks that are so shaped and thickened as to provide a center opening, which shall meet the rules governing openings and reinforcements contained elsewhere in the Code. Length of thread shall be calculated for the opening design, but shall not be less than shown in Table UG-43. Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means. When seal welding is employed in the installation of a threaded nozzle, the work shall be performed and inspected in the shop of the vessel manufacturer. Seal welding shall comply with UF-32.

INSPECTION AND TESTS

UF-45 GENERAL

The rules in the following paragraphs apply specifically to the inspection and testing of forged vessels and their component parts. These rules shall be used to supplement the applicable requirements for inspection and tests given throughout this Part and in UG-90 through UG-102. All forged vessels shall be examined as manufacture proceeds, to assure freedom from loose scale, gouges or grooves, and cracks or seams that are visible. After fabrication has passed the machining stage, the vessel body shall be measured at suitable intervals along its length to get a record of variations in wall thickness, and the nozzles for connecting piping and other important details shall be checked for conformity to the design dimensions.

UF-46 ACCEPTANCE BY INSPECTOR

Surfaces which are not to be machined shall be carefully inspected for visible defects such as seams, laps, or folds. On surfaces to be machined the inspection shall be made after machining. Regions from which defective material has been removed shall be inspected after removal and again after any necessary repair.

UF-47 PARTS FORGING

(a) When welding is used in the fabrication of parts forgings completed elsewhere, the parts forging manufacturer shall furnish a Nonmandatory Appendix W, Form U-2 Partial Data Report.

(b) All parts forgings completed elsewhere shall be marked with the manufacturer's name and the forging identification, including material designation. Should identifying marks be obliterated in the fabrication process, and for small parts, other means of identification shall be used. The forging manufacturer shall furnish reports of chemical and mechanical properties of the material and certification that each forging conforms to all requirements of Part UF.

(c) Parts forgings furnished as material for which parts Data Reports are not required need not be inspected at the plant of the forging manufacturer, but the manufacturer shall furnish a report of the extent and location of any repairs together with certification that they were made in accordance with all other requirements of UF-37 and UF-38. If desired, welding repairs of such forgings may be made, inspected, and tested at the shop of the pressure vessel manufacturer.

UF-52 CHECK OF HEAT TREATMENT AND POSTWELD HEAT TREATMENT (25)

The Inspector shall check the provisions made for heat treatment to ensure that the heat treatment is carried out in accordance with provisions of UF-31 and UF-32. The Inspector shall also verify that postweld heat treatment is done after repair welding when required under the rules of UF-37.

UF-53 TEST SPECIMENS

When test specimens are to be taken under the applicable specification, the Inspector shall be allowed to witness the selection, place the identifying stamping on them, and witness the testing of these specimens.

UF-54 TESTS AND RETESTS

Tests and retests shall be made in accordance with the requirements of the material specification.

UF-55 ULTRASONIC EXAMINATION (25)

(a) For vessels constructed of SA-372 Grade J, Class 110; or Grades N and P, Classes 100 and 120 material, the completed vessel after heat treatment shall be examined ultrasonically in accordance with SA-388. The reference specimen shall have the same nominal thickness, composition, and heat treatment as the vessel it represents. Angle beam examination shall be calibrated with a notch of a depth equal to 5% of the nominal section thickness, a length of approximately 1 in. (25 mm), and a width not greater than twice its depth.

(b) A vessel is unacceptable if examination results show one or more imperfections which produce indications exceeding in amplitude the indication from the calibrated notch. Round bottom surface imperfections, such as pits, scores, and conditioned areas, producing indications exceeding the amplitude of the calibrated notch shall be acceptable if the thickness below the indication is not less than the design wall thickness of the vessel, and its sides are faired to a ratio of not less than three to one.

MARKING AND REPORTS

UF-115 GENERAL

The rules of UG-115 through UG-120 shall apply to forged vessels as far as practicable. Vessels constructed of liquid quenched and tempered material, other than austenitic steels, shall be marked on the thickened head, unless a nameplate is used.

PART UB
REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY BRAZING

GENERAL

(25) UB-1 SCOPE

(a) The rules in Part UB are applicable to pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsections C and D.

(b) Definition. The term brazing as used in Part UB is defined as a group of welding processes that produce coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having liquidus above 840°F (450°C) and below the solidus of the base metal. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

(c) Specific brazing processes which are permitted for use under this Division are classified by method of heating as follows:

(1) torch brazing
(2) furnace brazing
(3) induction brazing
(4) electrical resistance brazing
(5) dip brazing — salt and flux bath

UB-2 ELEVATED TEMPERATURE

Operating temperature is dependent on the brazing filler metal as well as on the base metals being joined. The maximum allowable operating temperatures for the brazing filler metals are shown in Table UB-2.

UB-3 SERVICE RESTRICTIONS

Brazed vessels shall not be used for services as follows:

(a) lethal services as defined in UW-2(a)
(b) unfired steam boilers [see U-1(g)(1)]
(c) direct firing [see UW-2(d)]

MATERIALS

UB-5 GENERAL

(a) Materials used in the construction of pressure vessels and parts thereof by brazing shall conform to the specifications in Section II and shall be limited to those materials for which allowable stress values have been assigned in the tables referenced by UG-23.

(b) Combinations of dissimilar metals may be joined by brazing provided they meet the qualification requirements of Section IX, and the additional requirements of UB-12 when applicable.

Table UB-2
Maximum Design Temperatures for Brazing Filler Metal

Filler Metal Classification	Column 1 Temperature, °F (°C), Below Which Section IX Tests Only Are Required	Column 2 Temperature Range, °F (°C), Requiring Section IX and Additional Tests
BCuP	300 (150)	300–350 (150–180)
BAg	400 (200)	400–500 (200–260)
BCuZn	400 (200)	400–500 (200–260)
BCu	400 (200)	400–650 (200–340)
BAlSi	300 (150)	300–350 (150–180)
BNi	1,200 (650)	1,200–1,500 (650–815)
BAu	800 (430)	800–900 (430–480)
BMg	250 (120)	250–275 (120–135)

GENERAL NOTE: Temperatures based on AWS recommendations.

UB-6 BRAZING FILLER METALS

The selection of the brazing filler metal for a specific application shall depend upon its suitability for the base metals being joined and the intended service. Satisfactory qualification of the brazing procedure under Section IX and when necessary based on design temperature, with the additional requirements of this Section, is considered proof of the suitability of the filler metal. Brazing with brazing filler metals other than those listed in Section II, Part C, SFA-5.8 shall be separately qualified for both procedure and performance qualification in accordance with Section IX and when necessary with the additional requirements of this Section.

UB-7 FLUXES AND ATMOSPHERES

Suitable fluxes or atmospheres or combinations of fluxes and atmospheres shall be used to prevent oxidation of the brazing filler metal and the surfaces to be joined. Satisfactory qualification of the brazing procedure under Section IX and when necessary based on design temperature, with the additional requirements of this Section, is considered proof of the suitability of the flux and/or atmosphere.

DESIGN

(25) UB-9 GENERAL

The rules in the following paragraphs apply specifically to pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the general requirements for *Design* in Subsection A, and the specific requirements for *Design* in Subsections C and D.

UB-10 STRENGTH OF BRAZED JOINTS

It is the responsibility of the Manufacturer to determine from suitable tests or from experience that the specific brazing filler metal selected can produce a joint which will have adequate strength at design temperature. The strength of the brazed joint shall not be less than the strength of the base metal, or the weaker of two base metals in the case of dissimilar metal joints.

UB-11 QUALIFICATION OF BRAZED JOINTS FOR DESIGN TEMPERATURES UP TO THE MAXIMUM SHOWN IN COLUMN 1 OF TABLE UB-2

Satisfactory qualification of the brazing procedure in accordance with Section IX, Part QB is considered evidence of the adequacy of the base materials, the brazing filler metal, the flux and/or atmosphere, and other variables of the procedure.

UB-12 QUALIFICATION OF BRAZED JOINTS FOR DESIGN TEMPERATURES IN THE RANGE SHOWN IN COLUMN 2 OF TABLE UB-2

For design temperatures in the range shown in Column 2 of Table UB-2, tests in addition to those in UB-11 are required. These tests shall be considered a part of the qualification procedure. For such design temperatures, two tension tests on production type joints are required, one at the design temperature, T, and one at $1.05T$. Neither of these production type joints shall fail in the braze metal.

UB-13 CORROSION

(a) Provision shall be made for corrosion in accordance with the requirements in UG-25.

(b) Corrosion of the brazing filler metal and galvanic action between the brazing filler metal and the base metals shall be considered in selecting the brazing filler metal.

(c) The plate thickness in excess of that computed for a seamless vessel taking into account the applicable loadings in UG-22 may be taken as allowance for corrosion in vessels that have longitudinal joints of double-strap butt joint construction. Additional corrosion allowance shall be provided when needed, particularly on the inner buttstraps.

(d) The rules in this Part are not intended to apply to brazing used for the attachment of linings of corrosion resistant material that are not counted on to carry load.

UB-14 JOINT EFFICIENCY FACTORS

(a) The joint efficiency factor to be used in the appropriate design equations of pressure vessels and parts thereof shall be 1.0 for joints in which visual examination assures that the brazing filler metal has penetrated the entire joint [see Figure UB-14, sketch (a)].

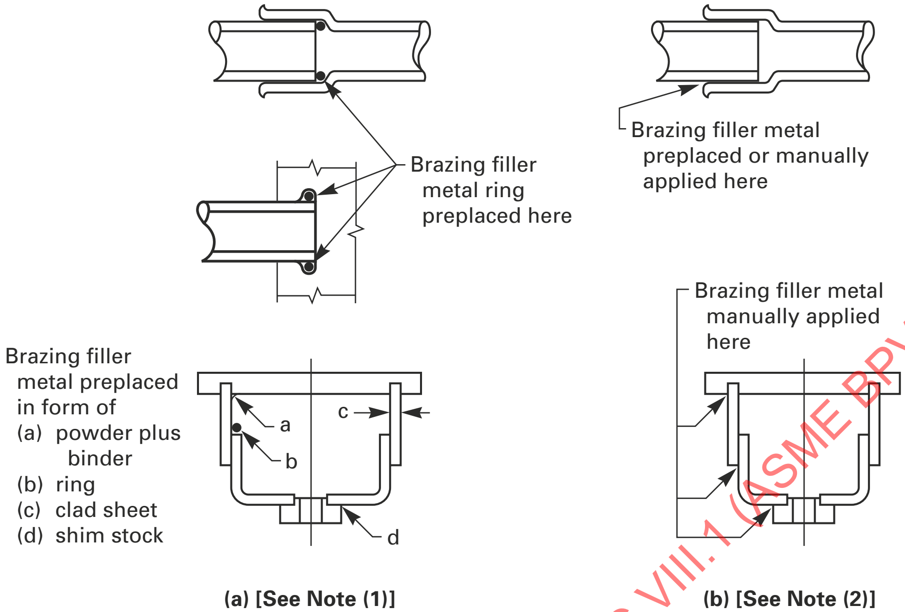
(b) The joint efficiency factor to be used in the appropriate design equations of pressure vessels and parts thereof shall be 0.5 for joints in which visual examination will not provide proof that the brazing filler metal has penetrated the entire joint. [see Figure UB-14, sketch (b); UB-15(b) and UB-15(c).]

(c) The appropriate joint efficiency factor to be used in design equations for seamless flat heads and seamless formed heads, excluding seamless hemispherical heads, is 1.0. The appropriate joint efficiency factor to be used in design equations for circumferential stress in seamless cylindrical or conical shells is 1.0.

UB-15 APPLICATION OF BRAZING FILLER METAL

(a) The design shall provide for the application of the brazing filler metal as part of the design of the joint. Where practicable, the brazing filler metal shall be applied in such a manner that it will flow into the joint or be distributed across the joint and produce visible evidence that it has penetrated the joint.

Figure UB-14
Examples of Filler Metal Application



NOTES:
(1) A 1.0 factor may be used in design.
(2) A 0.5 factor may be used in design.

(b) Manual Application. The manual application of the brazing filler metal by face feeding to a joint should be from the one side only. Visual observation of the other side of the joint will then show if the required penetration of the joint by the filler metal has been obtained. If the side opposite to the filler metal application cannot be visually examined, as is the case with socket type joints in pipe and tubing (blind joint), a joint efficiency factor of 0.5 shall be used in design of this joint as provided in UB-14(b).

(c) Preplaced Brazing Filler Metal. The brazing filler metal may be preplaced in the form of slugs, powder, rings, strip, cladding, spraying or other means. After brazing, the brazing filler metal should be visible on both sides of the joint. If the brazing filler metal is preplaced within a blind joint in such a manner that it penetrates the major portion of the joint during brazing and appears at the visible side of the joint, a joint efficiency factor of 1.0 may be used in the design of the joint. If the brazing filler metal is preplaced on the outside or near the outside of a blind joint, and the other side cannot be inspected to ascertain complete penetration, then a joint efficiency factor of 0.5 shall be used in the design of the joint as provided in UB-14(b). Figure UB-14 illustrates a few examples of this rule.

UB-16 PERMISSIBLE TYPES OF JOINTS

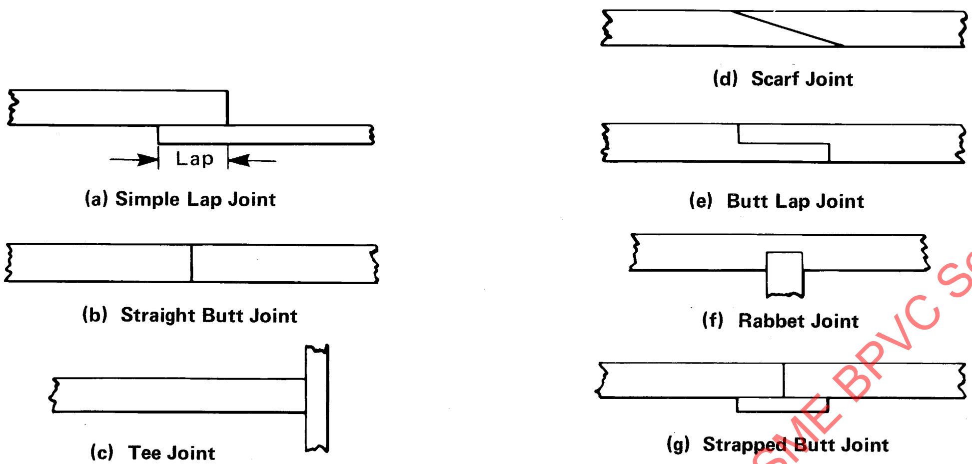
(a) Some permissible types of brazed joints are shown in Figure UB-16. For any type of joint, the strength of the brazed section shall exceed that of the base metal portion of the test specimen in the qualification tension tests provided for in Section IX, QB-150. Lap joints shall have a sufficient overlap to provide a higher strength in the brazed joint than in the base metal.

(b) The nominal thickness of base material used with lap joints tested using the test fixture shown in Section IX, Figure QB-462.1(e) shall not exceed $^1/_2$ in. (13 mm). There is no thickness limitation when specimens are tested without the test fixture shown in Section IX, Figure QB-462.1(e).

UB-17 JOINT CLEARANCE

The joint clearance shall be kept sufficiently small so that the filler metal will be distributed by capillary attraction. Since the strength of a brazed joint tends to decrease as the joint clearance used is increased, the clearances for the assembly of joints in pressure vessels or parts thereof shall be within the tolerances set up by the joint design and as used for the corresponding qualification specimens made in accordance with Section IX and UB-12 where applicable.

Figure UB-16
Some Acceptable Types of Brazed Joints



GENERAL NOTE: Other equivalent geometries yielding substantially equal results are also acceptable.

NOTE: For guidance, see Table UB-17 which gives recommended joint clearances at brazing temperature for various types of brazing filler metal. Brazing alloys will exhibit maximum unit strength if clearances are maintained within these limits.

UB-18 JOINT BRAZING PROCEDURE

A joint brazing procedure shall be developed for each different type of joint of a brazed assembly. A recommended form for recording the brazing procedure is shown in Section IX, Form QB-482. If more than one joint occurs in a brazed assembly, the brazing sequence shall be specified on the drawing or in instructions accompanying the drawing. If welding and brazing are to be done on the same assembly, the welding shall precede the brazing unless it is determined that the heat of welding will not adversely affect the braze previously made.

Table UB-17
Recommended Joint Clearances at Brazing Temperature

Brazing Filler Metal	Clearance, in. (mm) [Note (1)]
BAlSi	0.006–0.010 (0.15–0.25) for laps less than or equal to $^1/_4$ in. (6 mm)
	0.010–0.025 (0.25–0.64) for laps greater than $^1/_4$ in. (6 mm)
BCuP	0.001–0.005 (0.02–0.13)
BAg	0.002–0.005 (0.05–0.13)
BCuZn	0.002–0.005 (0.05–0.13)
BCu	0.000–0.002 (0.05–0.13) [Note (2)]
BNi	0.001–0.005 (0.02–0.13)

NOTES:
(1) In the case of round or tubular members, clearance on the radius is intended.
(2) For maximum strength, use the smallest possible clearance.

UB-19 OPENINGS

(a) Openings for nozzles and other connections shall be far enough away from any main brazed joint so that the joint and the opening reinforcement plates do not interfere with one another.

(b) Openings for pipe connections in vessels having brazed joints may be made by inserting pipe couplings, not exceeding NPS 3 (DN 80), or similar devices in the shell or heads and securing them by welding, without necessitating the application of the restrictive stamping provisions of UG-116, provided the welding is performed by welders who have been qualified under the provisions of Section IX for the welding position and type of joint used. Such attachments shall conform to the rules for welded connections in UW-15 and UW-16.

UB-20 NOZZLES

(a) Nozzles may be integral or attached to the vessel by any of the methods provided for in UG-43.

(b) For nozzle fittings having a bolting flange and an integral flange for brazing, the thickness of the flange attached to the pressure vessel shall not be less than the thickness of the neck of the fitting.

UB-21 BRAZED CONNECTIONS

Connections, such as saddle type fittings and fittings inserted into openings formed by outward flanging of the vessel wall, in sizes not exceeding NPS 3 (DN 80), may be attached to pressure vessels by lap joints of brazed construction. Sufficient brazing shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcement as prescribed in UG-41 through shear in the brazing.

UB-22 LOW TEMPERATURE OPERATION

Impact tests shall be made of the brazed joints in pressure vessels and parts thereof fabricated from materials for which impact tests are required in Subsection C. The tests shall be made in accordance with UG-84 except that terms referring to welding shall be interpreted as referring to brazing.

FABRICATION

(25) ## UB-30 GENERAL

(a) The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsections C and D.

(b) Each manufacturer or contractor shall be responsible for the quality of the brazing done by its own organization and shall conduct tests not only of the brazing procedure to determine its suitability to ensure brazes which will meet the required tests, but also of the brazers and brazing operators to determine their ability to apply the procedure properly.

(c) No production work shall be undertaken until both the brazing procedure and the brazers or brazing operators have been qualified.

(d) The Manufacturer (Certificate Holder) may engage individuals by contract or agreement for their services as brazers at the shop location shown on the Certificate of Authorization and at field sites (if allowed by the Certificate of Authorization) for the construction of pressure vessels or vessel parts, provided all the following conditions are met:

(1) All Code construction shall be the responsibility of the Manufacturer.

(2) All brazing shall be performed in accordance with the Manufacturer's Brazing Procedure Specifications which have been qualified by the Manufacturer in accordance with the requirements of Section IX.

(3) All brazers shall be qualified by the Manufacturer in accordance with the requirements of Section IX.

(4) The Manufacturer's Quality Control System shall include as a minimum:

(-a) a requirement for complete and exclusive administrative and technical supervision of all brazers by the Manufacturer;

(-b) evidence of the Manufacturer's authority to assign and remove brazers without the involvement of any other organization;

(-c) a requirement for assignment of brazer identification symbols;

(-d) evidence that this program has been accepted by the Manufacturer's Authorized Inspection Agency which provides the inspection service.

(5) The Manufacturer shall be responsible for Code compliance of the vessel or part, including Certification Mark stamping and providing completed Data Report Forms.

UB-31 QUALIFICATION OF BRAZING PROCEDURE

(a) Each procedure of brazing that is to be followed in construction shall be recorded in detail by the Manufacturer. Each brazing procedure shall be qualified in accordance with Section IX and when necessary determined by design temperature, with the additional requirements of this Section.

(b) The procedure used in brazing pressure parts and in joining load-carrying nonpressure parts, such as all permanent or temporary clips and lugs, to pressure parts shall be qualified in accordance with Section IX.

(c) The procedure used in brazing nonpressure-bearing attachments which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.) to pressure parts shall meet the following requirements:

(1) When the brazing process is manual, machine, or semiautomatic, procedure qualification is required in accordance with Section IX.

(2) When the brazing is any automatic brazing process performed in accordance with a Brazing Procedure Specification (in compliance with Section IX as far as applicable), procedure qualification testing is not required.

(d) Brazing of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. Qualification of a brazing procedure by one Manufacturer shall not qualify that procedure for any other Manufacturer, except as provided in Section IX, QG-106.

UB-32 QUALIFICATION OF BRAZERS AND BRAZING OPERATORS

(a) The brazers and brazing operators used in brazing pressure parts and in joining load-carrying nonpressure parts (attachments) to pressure parts shall be qualified in accordance with Section IX.

The qualification test for brazing operators of machine brazing equipment shall be performed on a separate test plate prior to the start of brazing or on the first workpiece.

(b) The brazers and brazing operators used in brazing non-pressure-bearing attachments, which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.), to pressure parts shall comply with the following:

(1) When the brazing process is manual, machine, or semiautomatic, qualification in accordance with Section IX is required.

(2) When brazing is done by any automatic brazing process, performance qualification testing is not required.

(c) Each brazer or brazing operator shall be assigned an identifying number, letter, or symbol by the Manufacturer which shall be used to identify the work of that brazer or brazing operator in accordance with UW-37(f).

(d) The Manufacturer shall maintain a record of the brazers and brazing operators showing the date and result of tests and the identification mark assigned to each. These records shall be maintained in accordance with Section IX.

(e) Brazing of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. A performance qualification test conducted by one Manufacturer shall not qualify a brazer or brazing operator to do work for any other Manufacturer.

UB-33 BUTTSTRAPS

(a) Buttstraps shall be formed to the curvature of the shell with which they are to be used.

(b) When the buttstraps of a longitudinal joint do not extend the full length of a shell section, the abutting edges of the shell plate may be welded provided the length of the weld between the end of the buttstraps and the edge of the head or adjoining shell plate is not greater than four times the shell plate thickness. When so constructed, the restrictive stamping provisions of UG-116 shall not apply provided the welding is performed by welders who have been qualified under the provisions of Section IX for the welding position and type of joint used. The welds shall be completed before brazing is begun.

UB-34 CLEANING OF SURFACES TO BE BRAZED

The surfaces to be brazed shall be clean and free from grease, paint, oxides, scale and foreign matter of any kind. Any chemical or mechanical cleaning method may be used that will provide a surface suitable for brazing.

UB-35 CLEARANCE BETWEEN SURFACES TO BE BRAZED

The clearances between surfaces to be brazed shall be maintained within the tolerances provided for by the joint design and used in the qualifying procedure. If greater tolerances are to be used in production, the joint must be requalified for those greater tolerances. The control of tolerances required may be obtained by using spot welding, crimping, or other means which will not interfere with the quality of the braze. If such means are employed in production, they must also be employed in qualification of procedure, brazer, and operator.

UB-36 POSTBRAZING OPERATIONS

Brazed joints shall be thoroughly cleaned of flux residue by any suitable means after brazing and prior to inspection.[50] Other postbrazing operations such as thermal treatments shall be performed in accordance with the qualified procedure.

UB-37 REPAIR OF DEFECTIVE BRAZING

Brazed joints which have been found to be defective may be rebrazed, where feasible, after thorough cleaning, and by employing the same brazing procedure used for the original braze. See UB-44. If a different brazing procedure is employed, i.e., torch repair of furnace brazed parts, a repair brazing procedure shall be established and qualified.

When a repair brazing procedure is established, it shall meet Section IX and other conditions set forth in this Section.

INSPECTION AND TESTS

UB-40 GENERAL (25)

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A and with the specific requirements for *Inspection and Tests* in Subsections C and D.

UB-41 INSPECTION DURING FABRICATION

The Manufacturer shall submit the vessel or other pressure parts for inspection at such stages of the work as may be designated by the Inspector.

UB-42 PROCEDURE (25)

The Inspector shall verify that the brazing procedure for each type of joint being produced is qualified in accordance with the requirements of Section IX and when necessary the additional requirements of this Section. The Inspector shall verify that each joint has been fabricated in accordance with the procedure. Where there is evidence of consistent poor quality, the Inspector shall have the right at any time to call for and witness tests of the brazing procedure.

UB-43 BRAZER AND BRAZING OPERATOR (25)

(a) The manufacturer shall certify that the brazing on a vessel or part thereof has been done by brazers or brazing operators who are qualified under the requirements of Section IX and the Inspector shall verify that only qualified brazers or brazing operators have been used.

(b) The manufacturer shall make available to the Inspector the record of the qualification tests of each brazer and brazing operator. The Inspector shall have the right at any time to call for and witness tests of the ability of a brazer or brazing operator.

(25) UB-44 VISUAL EXAMINATION

(a) Where possible, the Inspector shall visually inspect both sides of each brazed joint after flux residue removal. Where it is not possible to inspect one side of a brazed joint (blind joint), the Inspector shall check the design to determine that the proper joint factor has been employed, unless the Inspector can verify that the brazing filler metal has been preplaced in such a manner that it satisfies UB-15(b) and UB-15(c).

(b) There shall be evidence that the brazing filler metal has penetrated the joint. In a butt braze there shall be no concavity. The braze may be repaired or rebrazed.

(c) The presence of a crack in the brazing filler metal shall be cause for rejection. Dye penetrant inspection may be used if desired. The braze may be repaired or rebrazed. See UB-37.

(d) The presence of a crack in the base metal adjacent to a braze shall be cause for rejection even if the crack is filled with brazing alloy. Such cracking shall not be repaired.

(e) Pinholes or open defects in the braze shall be cause for rejection. The joint may be rebrazed.

(f) Rough fillets, particularly those with a convex appearance, are cause for rejection. Such joints may be repaired or rebrazed.

UB-50 EXEMPTIONS

Certain brazed joints regardless of their service temperatures may be exempt from the additional mechanical testing of this Section providing that the design application does not assume any benefit from the brazed joint strength. It shall, however, meet the requirements of those qualification tests required by Section IX of the Code.

MARKING AND REPORTS

UB-55 GENERAL

The provisions for marking and reports given in UG-115 through UG-120 shall apply without supplement to brazed pressure vessels and parts thereof.

SUBSECTION C
REQUIREMENTS PERTAINING TO CLASSES OF MATERIALS

PART UCS
REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF CARBON AND LOW ALLOY STEELS[51]

GENERAL

(25) UCS-1 SCOPE

The rules in Part UCS are applicable to pressure vessels and vessel parts that are constructed of carbon and low alloy steels and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements for *Fabrication* in Subsections B and D.

MATERIALS

UCS-5 GENERAL

(a) All carbon and low alloy steel material subject to stress due to pressure shall conform to one of the Specifications given in Section II and shall be limited to those listed in Table UCS-23 except as otherwise provided in UG-10 and UG-11.

(b) In addition to the requirements of UG-4(a), backing strips which remain in place need not conform to a material specification permitted by this Division if all of the following are met:

(1) The specification maximum composition limits or certificate values for the backing strip material shall not exceed those of the material specification for the pressure part to which it is attached.

(2) Either of the following requirements shall be met:

(-a) The backing strip base metal, and its associated HAZ, and the weld metal shall be impact tested in accordance with UG-84 at the MDMT shown on the nameplate with a butt weld test specimen to the pressure part material or to a material with the same P-No. and Group No. as the pressure part.

(-b) The material is assigned to Curve A and is exempt from impact testing at the MDMT shown on the nameplate by Figure UCS-66 (Figure UCS-66M) alone [i.e., MDMT reduction per Figure UCS-66.1 (Figure UCS-66.1M)] is not permitted], and both of the following apply:

(-1) The backing strip material specification minimum tensile strength shall not exceed that of the pressure part material specification.

(-2) The backing strip material specification minimum percent elongation shall be at least equal to that for the pressure part material specification.

(c) Carbon or low alloy steel having a carbon content of more than 0.35% by heat analysis shall not be used in welded construction or be shaped by oxygen cutting (except as provided in Part UF in this Division).

(d) Small parts used under the provisions of UG-11(a)(2) in welded construction shall be of good weldable quality.

UCS-6 STEEL PLATES

(a) Approved specifications for carbon and low alloy steel plates are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A (see UG-5).

(b) Steel plates conforming to SA-36; SA/CSA-G40.21 38W; SA/IS 2062 Grades E250A, E250BR, E250B0, and E250C; and SA-283 Grades C and D may be used for pressure parts in pressure vessels provided all of the following requirements are met:

(1) The vessels are not used to contain lethal substances, either liquid or gaseous.

(2) The material is not used in the construction of unfired steam boilers [see U-1(g)(1)].

(3) With the exception of flanges, flat bolted covers, and stiffening rings, the thickness of plates on which strength welding is applied does not exceed $^5/_8$ in. (16 mm).

(c) Except for local heating, such as cutting and welding, heating of SA-841 above 1,200°F (649°C) during fabrication is prohibited.

UCS-7 STEEL FORGINGS

Approved specifications for forgings of carbon and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A (see UG-6).

UCS-8 STEEL CASTINGS

Approved specifications for castings of carbon and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A. These stress values are to be multiplied by the casting quality factors of UG-24. Castings that are to be welded shall be of weldable grade.

UCS-9 STEEL PIPE AND TUBES

Approved specifications for pipe and tubes of carbon and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values of the materials from which the pipe or tubes are manufactured are given in Section II, Part D, Subpart 1, Table 1A. Net allowable stress values for pipe or tubes of welded manufacture are given in Section II, Part D, Subpart 1, Table 1A.

UCS-10 BOLT MATERIALS

(a) Approved specifications for bolt materials of carbon steel and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures (see UG-12) are given in Section II, Part D, Subpart 1, Table 3.

(b) Nonferrous and high alloy steel bolts, studs, and nuts may be used provided they are suitable for the application. They shall conform to the requirements of Part UNF or Part UHA, as applicable.

UCS-11 NUTS AND WASHERS

(a) Except as otherwise provided in (b)(4) below, materials for nuts shall conform to SA-194, SA-563, or to the requirements for nuts in the specification for the bolting material with which they are to be used. Nuts of special design, such as wing nuts, may be made of any suitable wrought material listed in Table UCS-23 or Table UHA-23 and shall be either: hot or cold forged; or machined from hot-forged, hot-rolled, or cold-drawn bars. Washers may be made from any suitable material listed in Tables UCS-23 and UHA-23.

(b) Materials for nuts and washers shall be selected as follows:

(1) Carbon steel nuts and carbon steel washers may be used with carbon steel bolts or studs.

(2) Carbon or alloy steel nuts and carbon or alloy steel washers of approximately the same hardness as the nuts may be used with alloy steel bolts or studs for metal temperatures not exceeding 900°F (480°C).

(3) Alloy steel nuts shall be used with alloy steel studs or bolts for metal temperatures exceeding 900°F (480°C). Washers, if used, shall be of alloy steel equivalent to the nut material.

(4) Nonferrous nuts and washers may be used with ferrous bolts and studs provided they are suitable for the application. Consideration shall be given to the differences in thermal expansion and possible corrosion resulting from the combination of dissimilar metals. Nonferrous nuts and washers shall conform to the requirements of UNF-13.

(c) Nuts shall be semifinished, chamfered, and trimmed. Nuts shall be threaded to Class 2B or finer tolerances according to ASME B1.1. For use with flanges conforming to the standards listed in UG-44(a), nuts shall conform at least to the dimensions given in ASME B18.2.2 for Heavy Series nuts. For use with connections designed in accordance with the rules in Mandatory Appendix 2, nuts may be of the ANSI Heavy Series, or they may be of other dimensions as permitted in (d) below.

(d) Nuts of special design or of dimensions other than ANSI Heavy Series may be used provided their strength is equal to that of the bolting, giving due consideration to bolt hole clearance, bearing area, thread form and class of fit, thread shear, and radial thrust from threads [see U-2(g)].

UCS-12 BARS AND SHAPES

(a) Approved specifications for bar and shape materials of carbon steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A.

(b) Bolt materials as described in UCS-10 may be used as bar materials.

(c) Parts made from bars, on which welding is done, shall be of material for which a P-Number for procedure qualification is given in Section IX, Table QW/QB-422 (see UW-5).

DESIGN

UCS-16 GENERAL (25)

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are constructed of carbon and low alloy steel and shall be used in conjunction with the general requirements for *Design* in Subsection A and with the specific requirements for *Design* in Subsections B and D.

UCS-19 WELDED JOINTS

When radiographic examination is required for butt-welded joints by UCS-57, Category A and B joints (see UW-3) shall be of Type No. (1) or No. (2) of Table UW-12.

UCS-23 MAXIMUM ALLOWABLE STRESS VALUES

Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other materials give the maximum allowable stress values at the temperature indicated for materials conforming to the specifications listed therein.[52] Values may be interpolated for intermediate temperatures. (See UG-23.) For vessels designed to operate at a temperature below −20°F (−29°C), the allowable stress values to be used in design shall not exceed those given in Section II, Part D, Subpart 1, Table 1A or Table 3 for 100°F (40°C).

UCS-27 SHELLS MADE FROM PIPE

(a) Shells of pressure vessels may be made from seamless pipe or tubing listed in Section II, Part D, Subpart 1, Table 1A, provided the material of the pipe is manufactured by the open-hearth, basic oxygen, or electric-furnace process.

(b) Shells of pressure vessels may be made from electric resistance-welded pipe or tubing listed in Section II, Part D, Subpart 1, Table 1A in nominal diameters up to

(25)

Table UCS-23
Carbon and Low Alloy Steel

Spec. No.	Type/Grade	Spec. No.	Type/Grade	Spec. No.	Type/Grade
SA-36	...	SA-334	1, 3, 6, 7, 9	SA-556	A2, B2, C2
SA-53	E/A, E/B, S/A, S/B	SA-335	P1, P2, P5, P5b, P5c, P9, P11, P12, P15, P21, P22, P91	SA-562	...
SA-105	...	SA-336	F1, F3V, F3VCb, F5, F5A, F9, F11 Cl. 2 & 3, F12, F21 Cl. 1 & 3, F22 Cl. 1 & 3, F22V, F91	SA-574	4037, 4042, 4140, 4340, 5137M, 51B37M
SA-106	A, B, C	SA-350	LF1, LF2, LF3, LF5, LF9	SA-587	...
SA-135	A, B	SA-352	LCB, LC1, LC2, LC3	SA-612	...
SA-178	A, C	SA-354	BC, BD	SA-662	A, B, C
SA-179	...	SA-369	FP1, FP2, FP5, FP9, FP11, FP12, FP21, FP22	SA-675	45, 50, 55, 60, 65, 70
SA-181	...	SA-372	A; B; C; D; E Cl. 55, 65, & 70; F Cl. 55, 65, & 70; G Cl. 55, 65, & 70; H Cl. 55, 65, & 70; J Cl. 55, 65, 70, & 110; L; M Cl. 85 & 100; N Cl. 100 & 120; P Cl. 100 & 120	SA-727	...
SA-182	FR, F1, F2, F3V, F3VCb, F5, F5a, F9, F11 Cl. 1 & 2, F12 Cl. 1 & 2, F21, F22 Cl. 1 & 3, F22V, F91	SA-387	2, 5, 11, 12, 21, 22, 91	SA-737	B, C
SA-192	...	SA-414	A, B, C, D, E, F, G	SA-738	A, B, C
SA-193	B5, B7, B7M, B16	SA-420	WPL 3, WPL 6, WPL 9	SA-739	B11, B22
SA-203	A, B, D, E, F	SA-423	1, 2	SA-765	I, II, III, IV
SA-204	A, B, C	SA-437	B4B, B4C	SA-832	21V, 22V, 23V
SA-209	T1, T1a, T1b	SA-449	...	SA-836	...
SA-210	A-1, C	SA-455	...	SA-841	A Cl. 1, B Cl. 2
SA-213	T2, T5, T5b, T5c, T9, T11, T12, T17, T21, T22, T91	SA-487	1 Cl. A & B, 2 Cl. A & B, 4 Cl. A, 8 Cl. A	SA-1008	CS-A, CS-B
SA-214	...	SA-508	1, 1A, 2 Cl. 1, 2 Cl. 2, 3 Cl. 1, 3 Cl. 2, 3V, 3VCb, 4N Cl. 3, 22 Cl. 3	SA/AS 1548	PT430, PT460, PT490
SA-216	WCA, WCB, WCC	SA-515	60, 65, 70	SA/CSA-G40.21	38W, 44W, 50W
SA-217	C12, C5, WC1, WC4, WC5, WC6, WC9	SA-516	55, 60, 65, 70	SA/EN 10028-2	P235GH, P265GH, P295GH, P355GH, 13CrMo4–5, 10CrMo9–10
SA-225	C	SA-524	I, II	SA/EN 10028-3	P275NH
SA-234	WPB, WPC, WPR, WP1, WP5, WP9, WP11 Cl. 1, WP12 Cl. 1, WP22 Cl. 1	SA-533	A Cl. 1 & 2, B Cl. 1 & 2, C Cl. 1 & 2, D Cl. 2, E Cl. 1 & 2	SA/EN 10216-2	P235GH, P265GH, 16Mo3, 13CrMo4–5, 10CrMo9–10
SA-250	T1, T1a, T1b	SA-537	Cl. 1, 2, & 3	SA/EN 10222-2	P280GH, P305GH, 13CrMo4–5, 11CrMo9–10
SA-266	1, 2, 3, 4	SA-540	B21, B22, B23, B24, B24V	SA/GB 713	Q345R
SA-283	C, D	SA-541	1, 1A, 2 Cl. 1, 2 Cl. 2, 3 Cl. 1, 3 Cl. 2, 3V, 3VCb, 22 Cl. 3, 22V	SA/IS 2062	E250A, E250BR, E250B0, E250C [Note (1)]
SA-285	A, B, C	SA-542	B Cl. 4, C Cl. 4a, D Cl. 4a, E Cl. 4a		
SA-299	A, B				
SA-302	A, B, C, D				
SA-307	A, B				
SA-320	L7, L7A, L7M, L43				
SA-325	1				
SA-333	1, 3, 4, 6, 7, 9				

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

NOTE:
(1) Refer to General Note (e)(3) in Figures UCS-66 and UCS-66M with regard to the normalized rolling condition for plates (products).

30 in. (750 mm)provided the material is manufactured by the open-hearth, basic oxygen, or electric-furnace process [see UG-16.4(b)].

UCS-28 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

(a) Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figures in Section II, Part D, Subpart 3 and the temperature limits of UG-20(c).

(b) Corrugated shells subject to external pressure may be used in pressure vessels in accordance with Section I, PFT-19.

UCS-29 STIFFENING RINGS FOR SHELLS UNDER EXTERNAL PRESSURE

Rules covering the design of stiffening rings are given in UG-29.

UCS-30 ATTACHMENT OF STIFFENING RINGS TO SHELL

Rules covering the attachment of stiffening rings are given in UG-30.

UCS-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

Ellipsoidal, torispherical, hemispherical, and conical heads having pressure on the convex side (minus heads) shall be designed by the rules of UG-33, using the applicable figures in Section II, Part D, Subpart 3.

(25) UCS-56 REQUIREMENTS FOR POSTWELD HEAT TREATMENT

UCS-56.1 Introduction. Before applying the requirements and exemptions in these paragraphs, qualification of the welding procedures shall be performed in accordance with Section IX, including conditions of postweld heat treatment (PWHT) or its omission, and the restrictions listed in this paragraph.

(a) All welds in pressure vessels or pressure vessel parts shall be given a PWHT, except as otherwise provided in the Notes to Tables UCS-56-1 through UCS-56-11.

(b) UW-40(f) provides detailed definitions for the nominal thickness to be used when determining PWHT requirements. Any corrosion allowance shall not be subtracted from the nominal thickness.

(c) The exemptions provided in Tables UCS-56-1 through UCS-56-11 or Table UCS-56-12 are not permitted when any of the following apply:

(1) PWHT is a service requirement as set forth in UCS-68.

(2) The electron beam welding process is used to weld ferritic materials greater than $^1/_8$ in. (3 mm) thick.

(3) The inertia and continuous drive friction welding processes are used to weld P-Nos. 3, 4, 5A, 5B, 5C, 10, and 15E materials of any thickness.

UCS-56.2 Exceptions. The following are exceptions to PWHT requirements:

(a) Except where prohibited in Tables UCS-56-1 through UCS-56-11, holding temperatures or holding times, or both, in excess of the minimum values given in Tables UCS-56-1 through UCS-56-11 may be used.

(b) Intermediate PWHT does not need to conform to the requirements of Tables UCS-56-1 through UCS-56-11.

(c) The holding time at temperature as specified in Tables UCS-56-1 through UCS-56-11 need not be continuous and may be an accumulation of time of multiple PWHT cycles.

UCS-56.3 Material Requirements. The materials in Tables UCS-56-1 through UCS-56-11 are listed in accordance with Section IX, Table QW/QB-422 and Table UCS-23. When there is a conflict in P-Number or Group Number, the numbers in Section IX govern.

(a) When non-pressure parts are welded to pressure parts, the PWHT temperature of the pressure part shall control.

(b) Electroslag welds in ferritic materials over $1^1/_2$ in. (38 mm) in thickness at the joint shall be given a grain-refining (austenitizing) heat treatment.

(c) Electrogas welds in ferritic materials with any single pass greater than $1^1/_2$ in. (38 mm) shall be given a grain-refining (austenitizing) heat treatment.

(d) For P-No. 1 materials only, the heating and cooling rate restrictions of UCS-56.5.1 and UCS-56.5.2 do not apply when the PWHT is in the austenitizing range.

UCS-56.4 Procedure. PWHT shall be carried out by one of the procedures given in UW-40, in accordance with UCS-56.5 and UCS-56.6. When a furnace is used to complete the PWHT, the following requirements apply:

(a) The temperature of the furnace shall not exceed 800°F (425°C) at the time the vessel or part is placed in the furnace.

(b) During the heating and holding periods, the furnace atmosphere shall be controlled to avoid excessive oxidation of the vessel surface.

(c) The furnace shall be designed to prevent direct flame impingement on the vessel.

UCS-56.5 Heating and Cooling Rate Requirements. The heating and cooling rate requirements in UCS-56.5.1 and UCS-56.5.2 apply to all PWHT procedures except where modified by Tables UCS-56-1 through UCS-56-11. The rates of heating and cooling should not be less than 100°F/hr (56°C/h). However, consideration of closed chambers and complex structures may dictate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

UCS-56.5.1 Heating Rate. The heating rate shall meet the following requirements:

(a) Above 800°F (425°C), the rate of heating shall not be more than 400°F/hr (222°C/h) divided by the maximum metal thickness of the shell or head material in inches. In no case shall the heating rate exceed 400°F/hr (222°C/h).

(b) During the heating period there shall not be a temperature variation greater than 250°F (140°C) within any 15-ft (4.6-m) interval throughout the portion of the vessel being heated.

(c) For tube-to-tubesheet welds, when PWHT is performed with no other components, the heating rate above 800°F (425°C) shall not exceed 250°F/hr (140°C/h) regardless of thickness.

UCS-56.5.2 Cooling Rate. The cooling rate shall meet the following requirements:

(a) Above 800°F (425°C), cooling shall be done in a closed furnace or cooling chamber at a rate not greater than 500°F/hr (280°C/h) divided by the maximum metal thickness of the shell or head material in inches. In no case shall the cooling rate exceed 500°F/hr (280°C/h).

(b) At temperatures above 800°F (425°C), there shall not be a temperature variation greater than 250°F (140°C) within any 15-ft (4.6-m) interval during the cooling phase.

(c) At 800°F (425°C) and below, the vessel may be cooled in still air.

(d) For tube-to-tubesheet welds, when PWHT is performed with no other components, the cooling rate above 800°F (425°C) shall not exceed 250°F/hr (140°C/h) regardless of thickness.

UCS-56.6 Soak Requirements. The vessel or vessel part shall be held at or above the temperature specified in Tables UCS-56-1 through UCS-56-11 or Table UCS-56-12 for the time specified in the tables. During the holding period, there shall not be a difference greater than 150°F (83°C) between the highest and lowest temperatures throughout the portion of the vessel being heated, except where a different range is specified in Tables UCS-56-1 through UCS-56-11. The holding temperature and time shall not be less than specified in Tables UCS-56-1 through UCS-56-11, except when the alternative requirements of Table UCS-56-12 are permitted and used.

UCS-56.7 Welded Repairs after PWHT. Vessels or parts of vessels that have received PWHT in accordance with the requirements of UCS-56 shall receive PWHT again after welded repairs have been made. However, welded repairs may be made after the final PWHT but prior to the final hydrostatic test, without additional PWHT, provided the following conditions are met:

(a) The welded repairs meet the requirements of UCS-56.7.1 through UCS-56.7.4.

(b) The materials are P-No. 1, Group Nos. 1, 2, and 3 or P-No. 3, Group Nos. 1, 2, and 3, including the weld metals used to join them.

(c) PWHT is not required as a service requirement in accordance with UCS-68 or UW-2(a), except for the exemptions in Tables UCS-56-1 through UCS-56-11.

UCS-56.7.1 General Requirements. Welded repairs shall meet the requirements of (a) through (c). The requirements do not apply when the welded repairs are minor restorations of the material surface, such as those required after removal of construction fixtures, and provided that the surface is not exposed to the vessel contents.

(a) The Manufacturer shall give prior notification of the repair to the user or the Authorized Inspector and shall not proceed until acceptance has been obtained. Such repairs shall be recorded on the Data Report.

(b) After removal of the defect, the groove shall be examined using either the magnetic particle examination (MT) method or the liquid penetrant examination (PT) method in accordance with Mandatory Appendix 6 for MT or Mandatory Appendix 8 for PT.

(c) In addition to the requirements of Section IX for qualification of Welding Procedure Specifications for groove welds, the following requirements shall apply:

(1) The weld metal shall be deposited by one or more of the following processes:

(-a) Shielded metal arc welding (SMAW) using low hydrogen electrodes with a maximum bead width of 4 times the electrode core diameter.

(-b) Gas tungsten arc welding (GTAW) with a maximum bead width of $^1/_2$ in. (13 mm).

(-c) Gas metal arc welding (GMAW) with a maximum bead width of $^1/_2$ in. (13 mm). When flux-cored filler materials are used, they shall be low hydrogen.

(-d) Submerged arc welding (SAW) using low-hydrogen consumables.

(-e) Plasma arc welding (PAW) with a maximum bead width of $^1/_2$ in. (13 mm).

(2) The low-hydrogen electrodes, filler materials, and consumables shall be properly conditioned in accordance with Section II, Part C.

UCS-56.7.2 Material Specific Requirements.

UCS-56.7.2.1 Repair to P-No. 1, Group Nos. 1, 2, and 3 After PWHT. Repairs after PWHT of P-No. 1, Group Nos. 1, 2, and 3 materials shall meet the following requirements:

(a) The total repair depth shall not exceed $1^1/_2$ in. (38 mm). The total depth of a weld repair shall be taken as the sum of the depths for repairs made from both sides of a weld at a given location.

(b) The repair area shall be preheated and maintained at a minimum temperature of 200°F (95°C) during welding.

UCS-56.7.2.2 Repair to P-No. 3, Group Nos. 1, 2, and 3 After PWHT. Repairs after PWHT of P-No. 3, Group Nos. 1, 2, and 3 materials shall be limited to the half bead weld repair and weld temper bead reinforcement technique using the following requirements:

(a) The total repair depth shall not exceed $^5/_8$ in. (16 mm). The total depth of a weld repair shall be taken as the sum of the depths for repairs made from both sides of a weld at a given location.

(b) The repair area shall be preheated and maintained at a minimum temperature of 350°F (175°C) during welding.

(c) The maximum interpass temperature shall be 450°F (230°C).

(d) The initial layer of weld metal shall be deposited over the entire area using $^1/_8$ in. (3 mm) maximum diameter electrodes.

(e) Approximately one-half the thickness of the first layer shall be removed by grinding before depositing subsequent layers.

(f) The subsequent weld layers shall be deposited using $^5/_{32}$ in. (4 mm) maximum diameter electrodes in such a manner as to ensure tempering of the prior weld beads and their heat-affected zones.

(g) A final temper bead weld shall be applied to a level above the surface being repaired without contacting the base material but close enough to the edge of the underlying weld bead to ensure tempering of the base material heat-affected zone.

(h) After completing all welding, the repair area shall be maintained at a temperature of 400°F to 500°F (205°C to 260°C) for a minimum period of 4 hr.

(i) The final temper bead reinforcement layer shall be removed substantially flush with the surface of the base material.

UCS-56.7.3 Inspection. After the finished repair weld has reached ambient temperature, it shall be inspected using the same nondestructive examination method that was used per UCS-56.7.1(b).

(a) For P-No. 3, Group No. 3 materials, the examination shall be made after the material has been at ambient temperature for a minimum of 48 hr to determine the presence of possible delayed cracking of the weld.

(b) If the examination is by the MT method, only the alternating current yoke technique is acceptable.

(c) In addition, welded repairs greater than $^3/_8$ in. (10 mm) deep in materials and welds that are required to be radiographed by the rules of this Division shall be radiographically examined to the requirements of UW-51.

UCS-56.7.4 Pressure Testing. The vessel shall be hydrostatically tested after making the welded repair.

UCS-56.8 Capacitance Discharge or Electrical Resistance Welding PWHT Requirements. Capacitor discharge or electric resistance welding may be used for attaching bare-wire thermocouples without subsequent PWHT, provided the energy output for welding is limited to 125 W-sec max. and any requirements specified in the Notes in Tables UCS-56-1 through UCS-56-11 shall apply. A Welding Procedure Specification shall be prepared with the contents specifying, as a minimum, the following:

(a) the capacitor discharge equipment

(b) the combination of materials to be joined

(c) the technique of application

Qualification of the welding procedure is not required.

Table UCS-56-1
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 1

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]	
		Up to 2 in. (50 mm)	Over 2 in. (50 mm)
P-No. 1 Gr. Nos. 1, 2, 3	1,100 (595)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)
Gr. No. 4	NA	None	None

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56-12.

(b) Postweld heat treatment is mandatory under the following conditions:

(1) for welded joints over 1$^1/_2$ in. (38 mm) nominal thickness;

(2) for welded joints over 1$^1/_4$ in. (32 mm) nominal thickness through 1$^1/_2$ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 200°F (95°C) during welding. This preheat need not be applied to SA-841 Grades A and B, provided that the carbon content and carbon equivalent (CE) for the plate material, by heat analysis, do not exceed 0.14% and 0.40%, respectively, where

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

(3) for welded joints of all thicknesses if required by UW-2, except postweld heat treatment is not mandatory under the conditions specified below:

(a) for groove welds not over $^1/_2$ in. (13 mm) size and fillet welds with a throat not over $^1/_2$ in. (13 mm) that attach nozzle connections that have a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or head thickness, and preheat to a minimum temperature of 200°F (95°C) is applied;

(b) for groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds with a throat thickness of $^1/_2$ in. (13 mm) or less that attach tubes to a tubesheet when the tube diameter does not exceed 2 in. (50 mm). A preheat of 200°F (95°C) minimum must be applied when the carbon content of the tubesheet exceeds 0.22%.

(c) for groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds with a throat thickness of $^1/_2$ in. (13 mm) or less used for attaching nonpressure parts to pressure parts. When the thickness of the pressure part exceeds 1$^1/_4$ in. (32 mm), preheat to a minimum temperature of 200°F (95°C) shall be applied prior to welding each pass;

(d) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of the pressure part exceeds 1$^1/_4$ in. (32 mm);

(e) for hard-facing weld metal overlay, corrosion resistant weld metal overlay, or for welds attaching corrosion resistant applied linings (see UCL-34), provided that when the thickness of the pressure part exceeds 1$^1/_4$ in. (32 mm), a preheat to a minimum temperature of 200°F (95°C) shall be applied and maintained during application of the first weld layer.

(c) NA = not applicable

Table UCS-56-2
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 3

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]	
		Up to 2 in. (50 mm)	Over 2 in. (50 mm)
P-No. 3 Gr. Nos. 1, 2, 3	1,100 (595)	1 hr/in. (25mm), 15 min minimum	2 hr plus 15 min for each additional inch (25mm) over 2 in. (50 mm)

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperatures specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56-12.

(b) Postweld heat treatment is mandatory on P-No. 3 Gr. No. 3 material in all thicknesses.

(c) Except for the exemptions in General Note (d), postweld heat treatment is mandatory under the following conditions:

(1) on P-No. 3 Gr. No. 1 and P-No. 3 Gr. No. 2 over $^5/_8$ in. (16 mm) nominal thickness. For these materials, postweld heat treatment is mandatory on material up to and including $^5/_8$ in. (16 mm) nominal thickness unless the deposited weld metal thickness qualified without postweld heat treatment in the welding procedure qualification test coupon is equal to or greater than the deposited weld metal thickness in the production weld.

(2) on material in all thicknesses if required by UW-2.

(d) For welding connections and attachments to pressure parts, postweld heat treatment is not mandatory under the conditions specified below:

(1) for attaching to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits) or nonpressure parts with groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds that have a throat thickness of $^1/_2$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;

(2) for circumferential butt welds between pipe, tube, and wrought or forged butt weld fittings where the material has both a nominal wall thickness of $^1/_2$ in. (13 mm) or less and a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);

(3) for studs welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is applied;

(4) for hard-facing weld metal overlay, corrosion resistant weld metal overlay, or for welds attaching corrosion resistant applied linings (see UCL-34), provided that when welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits), a preheat to a minimum temperature of 200°F (95°C) shall be applied and maintained during application of the first weld layer.

(5) for tubes or pressure-retaining handhole and inspection plugs or fittings that are secured by mechanical means (tube expansion, shoulder construction, machine threads, etc.) and seal welded, provided the seal weld has a throat thickness of $^3/_8$ in. (10 mm) or less, and preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of either part exceeds $^5/_8$ in. (16 mm).

Table UCS-56-3
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 4

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]	
		Up to 5 in. (125 mm)	Over 5 in. (125 mm)
P-No. 4 Gr. Nos. 1, 2	1,200 (650)	1 hr/in. (25mm), 15 min minimum	5 hr plus 15 min for each additional inch (25mm) over 5 in. (125 mm)

GENERAL NOTES:
(a) Except for exemptions in General Note (b), postweld heat treatment is mandatory under the following conditions:
(1) on material of all thicknesses if required by UW-2;
(2) on all other P-No. 4 Gr. Nos. 1 and 2 materials.
(b) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for circumferential butt welds between pipe, tube, and wrought or forged butt weld fittings that comply with the following conditions:
(a) a maximum nominal thickness of $^5/_8$ in. (16 mm);
(b) a maximum specified carbon content of not more than 0.15% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);
(c) a minimum preheat of 250°F (120°C).
(2) for pipe, tube, and wrought or forged fittings meeting the requirements of (1)(a) and (1)(b) above, having nonpressure attachments fillet welded to them, provided:
(a) the fillet welds have a maximum throat thickness of $^1/_2$ in. (13 mm);
(b) a minimum preheat temperature of 250°F (120°C) is applied.
(3) for pipe, tube, and wrought or forged fittings meeting the requirements of (1)(a) and (1)(b) above, having studs welded to them, a minimum preheat temperature of 250°F (120°C) is applied.
(4) for pipe, tube, and wrought or forged fittings meeting the requirements of (1)(a) and (1)(b) above, having extended heat absorbing fins electrically resistance welded to them, provided:
(a) the fins have a maximum thickness of $^1/_8$ in. (3 mm);
(b) prior to using the welding procedure, the Manufacturer shall demonstrate that the heat-affected zone does not encroach upon the minimum pipe or tube wall thickness.
(5) for tubes or pressure-retaining handhole and inspection plugs or fittings that are secured by mechanical means (tube expansion, shoulder construction, machine threads, etc.) and seal welded, provided the seal weld has a throat thickness of $^3/_8$ in. (10 mm) or less, and preheat to a minimum temperature of 250°F (120°C) is applied when the thickness of either part exceeds $^5/_8$ in. (16 mm).

(25)

Table UCS-56-4
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-Nos. 5A, 5B, and 5C

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]	
		Up to 5 in. (125 mm)	Over 5 in. (125 mm)
P-Nos. 5A, 5B Gr. No. 1, and 5C Gr. No. 1	1,250 (675)	1 hr/in. (25mm), 15 min minimum	5 hr plus 15 min for each additional inch (25mm) over 5 in. (125 mm)

GENERAL NOTES:

(a) Except for exemptions in General Notes (b) and (d), postweld heat treatment is mandatory under all conditions.

(b) Postweld heat treatment is not mandatory under the following conditions:

(1) for circumferential butt welds between pipe, tube, and wrought or forged butt weld fittings that comply with all of the following conditions:

(a) a maximum specified chromium content of 3.00%;

(b) a maximum nominal thickness of $^5/_8$ in. (16 mm);

(c) a maximum specified carbon content of not more than 0.15% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);

(d) a minimum preheat of 300°F (150°C) is applied.

(2) for pipe, tube, and wrought or forged fittings meeting the requirements of (1)(a), (1)(b), and (1)(c) having nonpressure attachments fillet welded to them, provided:

(a) the fillet welds have a maximum throat thickness of $^1/_2$ in. (13 mm);

(b) a minimum preheat temperature of 300°F (150°C) is applied.

(3) for pipe, tube, and wrought or forged fittings meeting the requirements of (1)(a), (1)(b), and (1)(c) having studs welded to them, provided a minimum preheat temperature of 300°F (150°C) is applied.

(4) for pipe, tube, and wrought or forged fittings meeting the requirements of (1)(a) and (1)(b) above, having extended heat absorbing fins electrically resistance welded to them, provided:

(a) the fins have a maximum thickness of $^1/_8$ in. (3 mm);

(b) prior to using the welding procedure, the Manufacturer shall demonstrate that the heat-affected zone does not encroach upon the minimum pipe or tube wall thickness.

(5) for tubes or pressure-retaining handhole and inspection plugs or fittings in P-No. 5A materials with a specified maximum chromium content of 6% that are secured by mechanical means (tube expansion, shoulder construction, machine threads, etc.) and seal welded, provided the seal weld has a throat thickness of $^3/_8$ in. (10 mm) or less, and preheat to a minimum temperature of 300°F (150°C) is applied when the thickness of either part exceeds $^5/_8$ in. (16 mm).

(c) When it is impractical to postweld heat P-Nos. 5A, 5B Gr. No. 1, and 5C Gr. No. 1 materials at the temperature specified in this Table, it is permissible to perform the postweld heat treatment at 1,200°F (650°C) minimum provided that, for material up to 2 in. (50 mm) nominal thickness, the holding time is increased to the greater of 4 hr minimum or 4 hr/in. (25 mm) of thickness; for thickness over 2 in. (50 mm), the specified holding times are multiplied by 4. The requirements of UCS-85 must be accommodated in this reduction in postweld heat treatment.

(d) Postweld heat treatment is not mandatory for attaching bare-wire thermocouples by capacitor discharge welding or electric resistance welding, provided

(1) the requirements of UCS-56.8 are met

(2) the maximum carbon content of the base material is restricted to 0.15%

(3) the minimum wall thickness is 0.20 in. (5 mm)

Table UCS-56-5
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 9A

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]
P-No. 9A Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min for each additional inch (25 mm) over 1 in. (25 mm)

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures [1,000°F (540°C) minimum] for longer periods of time in accordance with Table UCS-56-12.

(b) Except for exemptions in General Note (c), postweld heat treatment is mandatory under the following conditions:

(1) on material over 5/8 in. (16 mm) nominal thickness. For material up to and including 5/8 in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless the deposited weld metal thickness qualified without postweld heat treatment in the welding procedure qualification test coupon is equal to or greater than the deposited weld metal thickness in the production weld.

(2) on material of all thicknesses if required by UW-2.

(c) Postweld heat treatment is not mandatory under conditions specified below:

(1) for circumferential butt welds in pipe or tubes where the pipe or tubes comply with all the following conditions:

(a) a maximum nominal outside diameter of 4 in. (100 mm) (DN 100);

(b) a maximum thickness of 1/2 in. (13 mm);

(c) a maximum specified carbon content of not more than 0.15% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);

(d) a minimum preheat of 250°F (120°C).

(2) for pipe or tube materials meeting the requirements of (1)(a), (1)(b), and (1)(c) above, having attachments fillet welded to them, provided:

(a) the fillet welds have a throat thickness of 1/2 in. (13 mm) or less;

(b) the material is preheated to 250°F (120°C) minimum. A lower preheating temperature may be used, provided specifically controlled procedures necessary to produce sound welded joints are used. Such procedures shall include but shall not be limited to the following:

(-1) The throat thickness of fillet welds shall be 1/2 in. (13 mm) or less.

(-2) The maximum continuous length of fillet welds shall be not over 4 in. (100 mm).

(-3) The thickness of the test plate used in making the welding procedure qualification of Section IX shall not be less than that of the material to be welded.

(3) for attaching nonpressure parts to pressure parts with groove welds not over 1/2 in. (13 mm) in size or fillet welds that have a throat thickness of 1/2 in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;

(4) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied;

(5) for hard-facing weld metal overlay, corrosion resistant weld metal overlay, or for welds attaching corrosion resistant applied linings (see UCL-34), provided that a preheat to a minimum temperature of 200°F (95°C) shall be applied and maintained during application of the first weld layer.

(d) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-6
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 9B

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]
P-No. 9B Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min for each additional inch (25 mm) over 1 in. (25 mm)

GENERAL NOTES:
(a) When it is impractical to postweld heat treat at the temperatures specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures [1,000°F (540°C) minimum] for longer periods of time in accordance with Table UCS-56-12.
(b) The holding temperature for postweld heat treatment shall not exceed 1,175°F (635°C).
(c) Except for exemptions in General Note (d), postweld heat treatment is mandatory under the following conditions:
(1) on material over $^5/_8$ in. (16 mm) nominal thickness. For material up to and including $^5/_8$ in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless the deposited weld metal thickness qualified without postweld heat treatment in the welding procedure qualification test coupon is equal to or greater than the deposited weld metal thickness in the production weld.
(2) on material of all thicknesses if required by UW-2.
(d) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for attaching nonpressure parts to pressure parts with groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds that have a throat thickness of $^1/_2$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;
(2) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied;
(3) for hard-facing weld metal overlay, corrosion resistant weld metal overlay, or for welds attaching corrosion resistant applied linings (see UCL-34), provided that a preheat to a minimum temperature of 200°F (95°C) shall be applied and maintained during application of the first weld layer.
(e) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-7
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10A

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]
P-No. 10A Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min for each additional inch (25 mm) over 1 in. (25 mm)

GENERAL NOTES:
(a) See below.
(1) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56-12.
(2) Consideration should be given for possible embrittlement of materials containing up to 0.15% vanadium when postweld heat treating at the minimum temperature and at lower temperature for longer holding times.
(b) Except for exemptions in General Note (c), postweld heat treatment is mandatory under the following conditions:
(1) on all thicknesses of SA-487 Class 1Q material;
(2) on all other P-No. 10A materials over $^5/_8$ in. (16 mm) nominal thickness. For these materials up to and including $^5/_8$ in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless the deposited weld metal thickness qualified without postweld heat treatment in the welding procedure qualification test coupon is equal to or greater than the deposited weld metal thickness in the production weld.
(3) on material of all thicknesses if required by UW-2.
(c) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for attaching to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits) or nonpressure parts with groove weld not over $^1/_2$ in. (13 mm) in size or fillet welds having a throat thickness of $^1/_2$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;
(2) for circumferential butt welds in pipes or tube where the pipe or tube has both a nominal wall thickness of $^1/_2$ in. (13 mm) or less and a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is applied;
(3) for studs welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is applied;
(4) for hard-facing weld metal overlay, corrosion resistant weld metal overlay, or for welds attaching corrosion resistant applied linings (see UCL-34), provided that when welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits), a preheat to a minimum temperature of 200°F (95°C) shall be applied and maintained during application of the first weld layer.
(d) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-8
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10B

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]
P-No. 10B Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min for each additional inch (25 mm) over 1 in. (25 mm)

GENERAL NOTES:
(a) Postweld heat treatment is mandatory for P-No. 10B materials for all thicknesses.
(b) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-9
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10C

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40.6]
P-No. 10C Gr. No. 1	1,000 (540)	1 hr minimum, plus 15 min for each additional inch (25 mm) over 1 in. (25 mm)

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperatures specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56-12.

(b) Except for exemptions in General Note (c), postweld heat treatment is mandatory under the following conditions:

(1) for material over 1$^1/_2$ in. (38 mm) nominal thickness. Postweld heat treatment is mandatory on materials over 1$^1/_4$ in. (32 mm) nominal thickness through 1$^1/_2$ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 200°F (95°C) during welding.

(2) on material of all thicknesses if required by UW-2.

(c) Postweld heat treatment is not mandatory under the conditions specified below:

(1) for groove welds not over $^1/_2$ in. (13 mm) in size and fillet welds with throat not over $^1/_2$ in. (13 mm) that attach nozzle connections that have a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or head thickness and preheat to a minimum temperature of 200°F (95°C) is applied;

(2) for groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds having throat thickness of $^1/_2$ in. (13 mm) or less used for attaching nonpressure parts to pressure parts and preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of the pressure part exceeds 1$^1/_4$ in. (32 mm);

(3) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of the pressure part exceeds 1$^1/_4$ in. (32 mm);

(4) for hard-facing weld metal overlay, corrosion resistant weld metal overlay, or for welds attaching corrosion resistant applied linings (see UCL-34), provided that when the thickness of the pressure part exceeds 1$^1/_4$ in. (32 mm), a preheat to a minimum temperature of 200°F (95°C) shall be applied and maintained during application of the first weld layer.

(d) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

(25)

Table UCS-56-11
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 15E

Material	Minimum Holding Temperature, °F (°C) [Note (1)] and [Note (2)]	Maximum Holding Temperature, °F (°C)	Minimum Holding Time at Normal Temperature for Weld Thickness (Nominal)	
			Up to 5 in. (125 mm)	Over 5 in. (125 mm)
P-No. 15E Group No. 1	1,300 (705)	[Note (3)] and [Note (4)]	1 hr/in. (2 min/mm), 30 min minimum	5 hr plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)

GENERAL NOTES:

(a) Postweld heat treatment is not mandatory for electric resistance welds used to attach extended heat-absorbing fins to pipe and tube materials, provided the following requirements are met:

(1) a maximum pipe or tube size of NPS 4 (DN 100)

(2) a maximum specified carbon content (SA material specification carbon content, except when further limited by the Purchaser to a value within the specification limits) of not more than 0.15%

(3) a maximum fin thickness of $^1/_8$ in. (3 mm)

(4) prior to using the welding procedure, the Manufacturer shall demonstrate that the heat-affected zone does not encroach upon the minimum wall thickness

(b) Postweld heat treatment is not mandatory for attaching bare-wire thermocouples by capacitor discharge welding or electric resistance welding, provided

(1) the requirements of UCS-56.8 are met

(2) the maximum carbon content of the base material is restricted to 0.15%

(3) the minimum wall thickness is 0.20 in. (5 mm)

NOTES:

(1) If the nominal weld thickness is ≤0.5 in. (13 mm), the minimum holding temperature is 1,250°F (675°C).

(2) For dissimilar metal welds (i.e., welds made between a P-No. 15E Group No. 1 and another lower chromium ferritic, austenitic, or nickel-based steel), if filler metal chromium content is less than 3.0% or if the filler metal is nickel-based or austenitic, the minimum holding temperature shall be 1,300°F (705°C).

(3) For welds made with matching Grade 91 filler metal (e.g., AWS A.5.5 E90xx-B91, ISO EN CrMo91), the maximum holding temperature shall be determined as follows:

(a) If the Ni + Mn content of the filler metal is less than or equal to 1.0%, the maximum PWHT temperature shall be 1,455°F (790°C).

(b) If the Ni + Mn content of the filler metal is greater than 1.0% but less than or equal to 1.2%, the maximum PWHT temperature shall be 1,435°F (780°C).

(c) If the Ni + Mn content of the filler metal is greater than 1.2%, the maximum PWHT temperature shall be at least 20°F (10°C) below the lower critical transformation temperature (Ac1) as determined by measurement of that temperature for the specific heat (or heats) of filler metal to be used in accordance with ASTM A1033; in such case the following additional restrictions will apply:

(1) The Ac1 temperature of the filler metal as measured in accordance with ASTM A1033 shall be included in the Manufacturer's Construction Records.

(2) The maximum operating temperature for any vessel constructed using filler metal with a Ni + Mn content in excess of 1.2% shall be 975°F (525°C).

The lower transformation temperature for matching filler material is affected by alloy content, primarily the total of Ni + Mn. The maximum holding temperature has been set to avoid heat treatment in the intercritical zone.

(d) If multiple welds made with matching Grade 91 filler metal in a pressure part or pressure vessel are to be postweld heat treated at the same time, the maximum PWHT temperature shall be determined based on the weld with the highest Ni + Mn content.

(4) If a portion of the component is heated above the heat treatment temperature allowed above, one of the following actions shall be performed:

(a) The component in its entirety must be renormalized and tempered.

(b) If the maximum holding temperature in Note (3)(b) above is exceeded, but does not exceed 1,470°F (800°C), the weld metal shall be removed and replaced.

(c) The portion of the component heated above 1,470°F (800°C) and at least 3 in. (75 mm) on either side of the overheated zone must be removed and be renormalized and tempered or replaced.

(d) The allowable stress shall be that for Grade 9 material (i.e., SA-213-T9, SA-335-P9, or equivalent product specification) at the design temperature, provided that the portion of the component heated to a temperature greater than that allowed above is reheat treated within the temperature range specified above. To apply the provisions of this paragraph, the Manufacturer shall have qualified a WPS with representative test specimens that accurately simulate the thermal history of the production part. Specifically, the qualification specimens shall first be heat treated at a similar temperature for a similar time that violates the maximum holding temperature limit and then shall receive a final heat treatment for the required time within the temperature range specified by this Table. The use of this provision shall be noted in the Manufacturer's Data Report.

UCS-57 RADIOGRAPHIC EXAMINATION

In addition to the requirements of UW-11, complete radiographic examination is required for each butt-welded joint at which the thinner of the plate or vessel wall thicknesses at the welded joint exceeds the thickness limit above which full radiography is required in Table UCS-57.

LOW TEMPERATURE OPERATION

UCS-65 SCOPE

The following paragraphs contain requirements for vessels and vessel parts constructed of carbon and low alloy steels with respect to minimum design metal temperatures.

(25) **UCS-66 MATERIALS**

(a) Unless exempted by the rules of UG-20(f) or other rules of this Division, Figure UCS-66 (Figure UCS-66M) shall be used to establish impact testing exemptions for steels listed in Part UCS. When Figure UCS-66 (Figure UCS-66M) is used, impact testing is required for a combination of minimum design metal temperature (see UG-20) and governing thickness (as defined below) that is below the curve assigned to the subject material. If a minimum design metal temperature and governing thickness combination is on or above the curve, impact testing is not required by the rules of this Division, except as required by (j) below and UCS-67 for weld metal. Components, such as shells, heads, nozzles, manways, reinforcing pads, stiffening rings, flanges, tubesheets, flat cover plates, backing strips which remain in place, and attachments that are essential to the structural integrity of the vessel when welded to pressure-retaining components, shall be treated as separate components. Each component shall be evaluated for impact test requirements based on its individual material classification, governing thickness as defined in (1) and (2) below, and the minimum design metal temperature.

(1) The following governing thickness definitions apply when using Figure UCS-66 (Figure UCS-66M):

(-a) Excluding castings, the governing thickness t_g of a welded part is as follows:

(-1) for butt joints except those in flat heads, tubesheets, and other flat components subjected to primary bending stress, the nominal thickness of the thickest welded joint [see Figure UCS-66.3, sketch (a)].

(-2) for corner, fillet, or lap-welded joints, including attachments as defined above, the thinner of the two parts joined.

(-3) for flat heads, tubesheets, and other flat components subjected to primary bending stress, the larger of (-2) above or the flat component thickness divided by 4.

(-4) for welded assemblies comprised of more than two components (e.g., nozzle-to-shell joint with reinforcing pad), the governing thickness and permissible minimum design metal temperature of each of the individual welded joints of the assembly shall be determined, and the warmest of the minimum design metal

(25) **Table UCS-56-12**
Alternative Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels

Decrease in Temperature Below Minimum Specified Temperature, °F (°C)	Minimum Holding Time [Note (1)] at Decreased Temperature, hr	Notes
≤50 (≤28)	2	...
100 (56)	4	...
150 (83)	10	(2)
200 (111)	20	(2)

GENERAL NOTES:
(a) Applicable only when permitted in Tables UCS-56-1 through UCS-56-11.
(b) Interpolation for time based on temperature reduction between values greater than 50°F (28°C) is permitted.

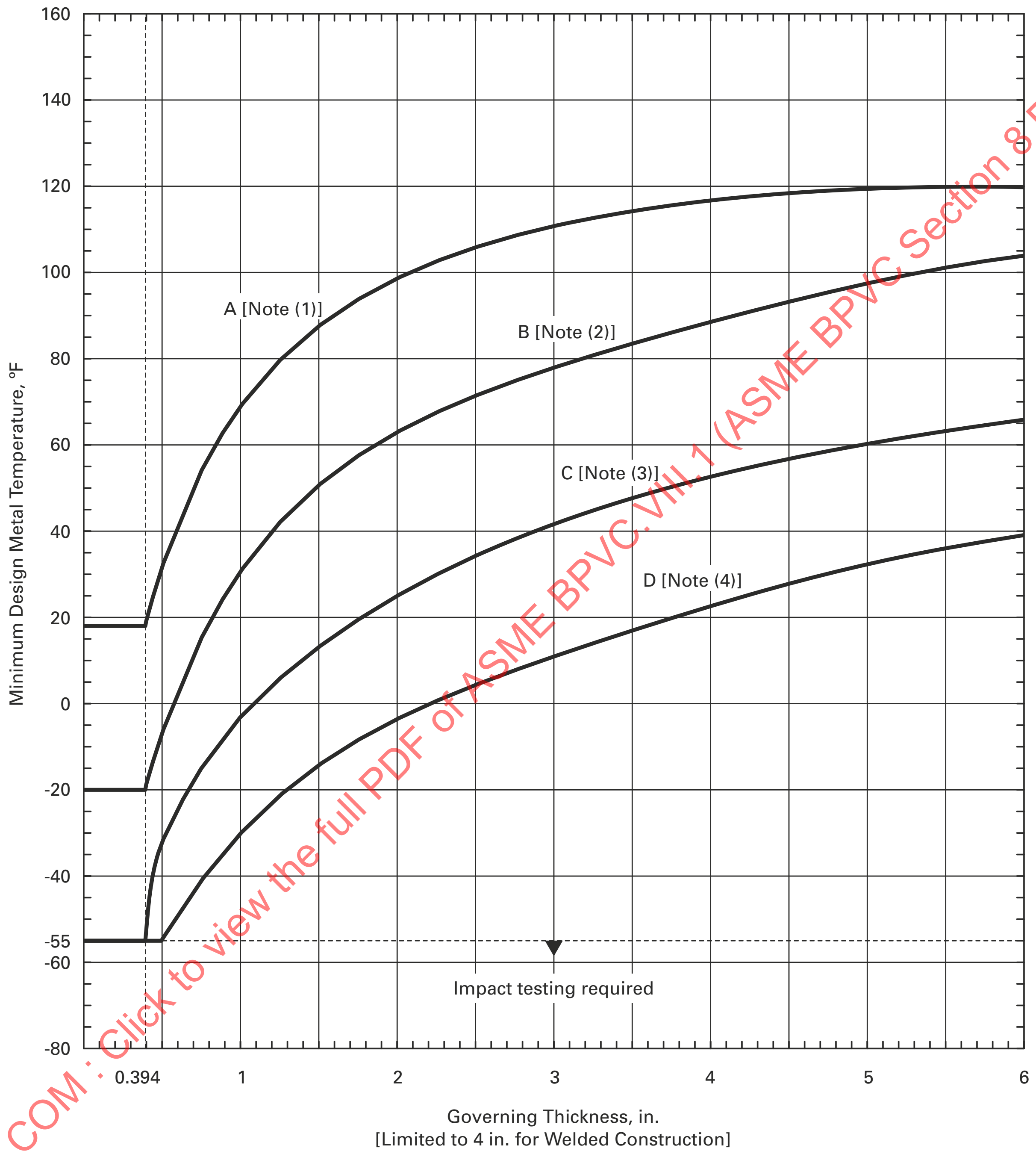
NOTES:
(1) Minimum holding time for 1 in. (25 mm) thickness or less. Add 15 min for each additional inch (25 mm) of thickness greater than 1 in. (25 mm).
(2) These lower postweld heat treatment temperatures permitted only for P-No. 1 Gr. Nos. 1 and 2 materials.

Table UCS-57
Thickness Above Which Full Radiographic Examination of Butt-Welded Joints Is Mandatory

P-No. and Group No. Classification of Material	Nominal Thickness Above Which Butt-Welded Joints Shall Be Fully Radiographed, in. (mm)
1 Gr. 1, 2, 3	$1^1/_4$ (32)
3 Gr. 1, 2, 3	$^3/_4$ (19)
4 Gr. 1, 2	$^5/_8$ (16)
5A Gr. 1, 2	0 (0)
5B Gr. 1	0 (0)
5C Gr. 1	0 (0)
15E, Gr. 1	0 (0)
9A Gr. 1	$^5/_8$ (16)
9B Gr. 1	$^5/_8$ (16)
10A Gr. 1	$^3/_4$ (19)
10B Gr. 1	$^5/_8$ (16)
10C Gr. 1	$^5/_8$ (16)

(25)

Figure UCS-66
Impact Test Exemption Curves



GENERAL NOTES:

(a) Tabular values for this figure are provided in Table UCS-66.

(b) See UCS-66(a).

(c) For bolting and nuts, the following impact test exemption temperatures shall apply:

Bolting

Spec. No.	Grade	Diameter, in. (mm)	Impact Test Exemption Temperature, °F (°C)
SA-193	B5	Up to 4 (100), incl.	−20 (−29)
SA-193	B7	Up to $2^1/_2$ in. (64), incl.	−55 (−48)
SA-193	...	Over $2^1/_2$ (64) to 7 (175), incl.	−40 (−40)
SA-193	B7M	Up to $2^1/_2$ (64), incl.	−55 (−48)

Figure UCS-66
Impact Test Exemption Curves (Cont'd)

GENERAL NOTES (CONT'D):

Table continued

Bolting

Spec. No.	Grade	Diameter, in. (mm)	Impact Test Exemption Temperature, °F (°C)
SA-193	B16	Up to $2\frac{1}{2}$ (64), incl.	−55 (−48)
SA-193	...	Over $2\frac{1}{2}$ (64) to 7 (175), incl.	−20 (−29)
SA-307	B	All	−20 (−29)
SA-320	L7, L7A, L7M	Up to $2\frac{1}{2}$ (64), incl.	See Figure UG-84.5-1, General Note (c)
SA-320	L43	Up to 1 (25), incl.	See Figure UG-84.5-1, General Note (c)
SA-325	1	$\frac{1}{2}$ (13) to $1\frac{1}{2}$ (38)	−20 (−29)
SA-354	BC	Up to 4 (100), incl.	0 (−18)
SA-354	BD	Up to 4 (100), incl.	+20 (−7)
SA-437	B4B, B4C	All diameters	See Figure UG-84.5-1, General Note (c)
SA-449	...	Up to 3 (75), incl.	−20 (−29)
SA-540	B21 Cl. All	All	Impact test required
SA-540	B22 Cl. 3	Up to 4 (100), incl.	Impact test required
SA-540	B23 Cl. 1, 2	All	Impact test required
SA-540	B23 Cl. 3, 4	Up to 6 (150), incl.	See Figure UG-84.5-1, General Note (c)
SA-540	B23 Cl. 3, 4	Over 6 (150) to $9\frac{1}{2}$ (240), incl.	Impact test required
SA-540	B23 Cl. 5	Up to 8 (200), incl.	See Figure UG-84.5-1, General Note (c)
SA-540	B23 Cl. 5	Over 8 (200) to $9\frac{1}{2}$ (240), incl.	Impact test required
SA-540	B24 Cl. 1	Up to 6 (150), incl.	See Figure UG-84.5-1, General Note (c)
SA-540	B24 Cl. 1	Over 6 (150) to 8 (200), incl.	Impact test required
SA-540	B24 Cl. 2	Up to 7 (175), incl.	See Figure UG-84.5-1, General Note (c)
SA-540	B24 Cl. 2	Over 7 (175) to $9\frac{1}{2}$ (240), incl.	Impact test required
SA-540	B24 Cl. 3, 4	Up to 8 (200), incl.	See Figure UG-84.5-1, General Note (c)
SA-540	B24 Cl. 3, 4	Over 8 (200) to $9\frac{1}{2}$ (240), incl.	Impact test required
SA-540	B24 Cl. 5	Up to $9\frac{1}{2}$ (240), incl.	See Figure UG-84.5-1, General Note (c)
SA-540	B24V Cl. 3	All	See Figure UG-84.5-1, General Note (c)

Nuts

Spec. No.	Grade	Impact Test Exemption Temperature, °F (°C)
SA-194	2, 2H, 2HM, 3, 4, 7, 7M, and 16	−55 (−48)
SA-540	B21/B22/B23/B24/B24V	−55 (−48)

(d) When no class or grade is shown, all classes or grades are included.

(e) The following shall apply to all material assignment notes:

(1) Cooling rates faster than those obtained by cooling in air, followed by tempering, as permitted by the material specification, are considered to be equivalent to normalizing or normalizing and tempering heat treatments.

(2) Fine grain practice is defined as the procedure necessary to obtain a fine austenitic grain size as described in SA-20.

(3) Normalized rolling condition is not considered as being equivalent to normalizing.

(f) Castings not listed in Notes (1) and (2) below shall be impact tested.

NOTES:

(1) Curve A applies to the following:

(a) all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below

(b) SA-216 Grades WCB and WCC if normalized and tempered or water-quenched and tempered; SA-217 Grade WC6 if normalized and tempered or water-quenched and tempered

(c) A/SA-105 forged flanges supplied in the as-forged condition

(d) SA/IS 2062 Grades E250A, E250BR, E250B0, and E250C supplied in the normalized rolling condition.

(2) Curve B applies to the following:

(a) see below:

A/SA-105 forged flanges produced to fine grain practice and normalized, normalized and tempered, or quenched and tempered after forging

SA-216 Grade WCA if normalized and tempered or water-quenched and tempered

SA-216 Grades WCB and WCC for thicknesses not exceeding 2 in. (50 mm) , if produced to fine grain practice and water-quenched and tempered

SA-217 Grade WC9 if normalized and tempered

Figure UCS-66
Impact Test Exemption Curves (Cont'd)

NOTES (CONT'D):

SA-285 Grades A and B
SA-299
SA-414 Grade A
SA-515 Grade 60
SA-516 Grades 65 and 70 if not normalized
SA-612 if not normalized
SA-662 Grade B if not normalized
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH as rolled
SA/AS 1548 Grades PT430NR and PT460NR
SA/GB 713 Grade Q345R if not normalized

(b) except for cast steels, all materials of Curve A, if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed in Curves C and D below

(c) all pipe, fittings, forgings and tubing not listed for Curves C and D below

(d) parts permitted under UG-11 even when fabricated from plate that otherwise would be assigned to a different curve

(3) Curve C applies to the following:

(a) see below:

SA-182 Grades F21 and F22 if normalized and tempered
SA-302 Grades C and D
SA-336 F21 and F22 if normalized and tempered, or liquid quenched and tempered
SA-387 Grades 21 and 22 if normalized and tempered, or liquid quenched and tempered
SA-516 Grades 55 and 60 if not normalized
SA-533 Types B and C Class 1
SA-662 Grade A
SA/EN 10028-2 Grade 10CrMo9–10 if normalized and tempered

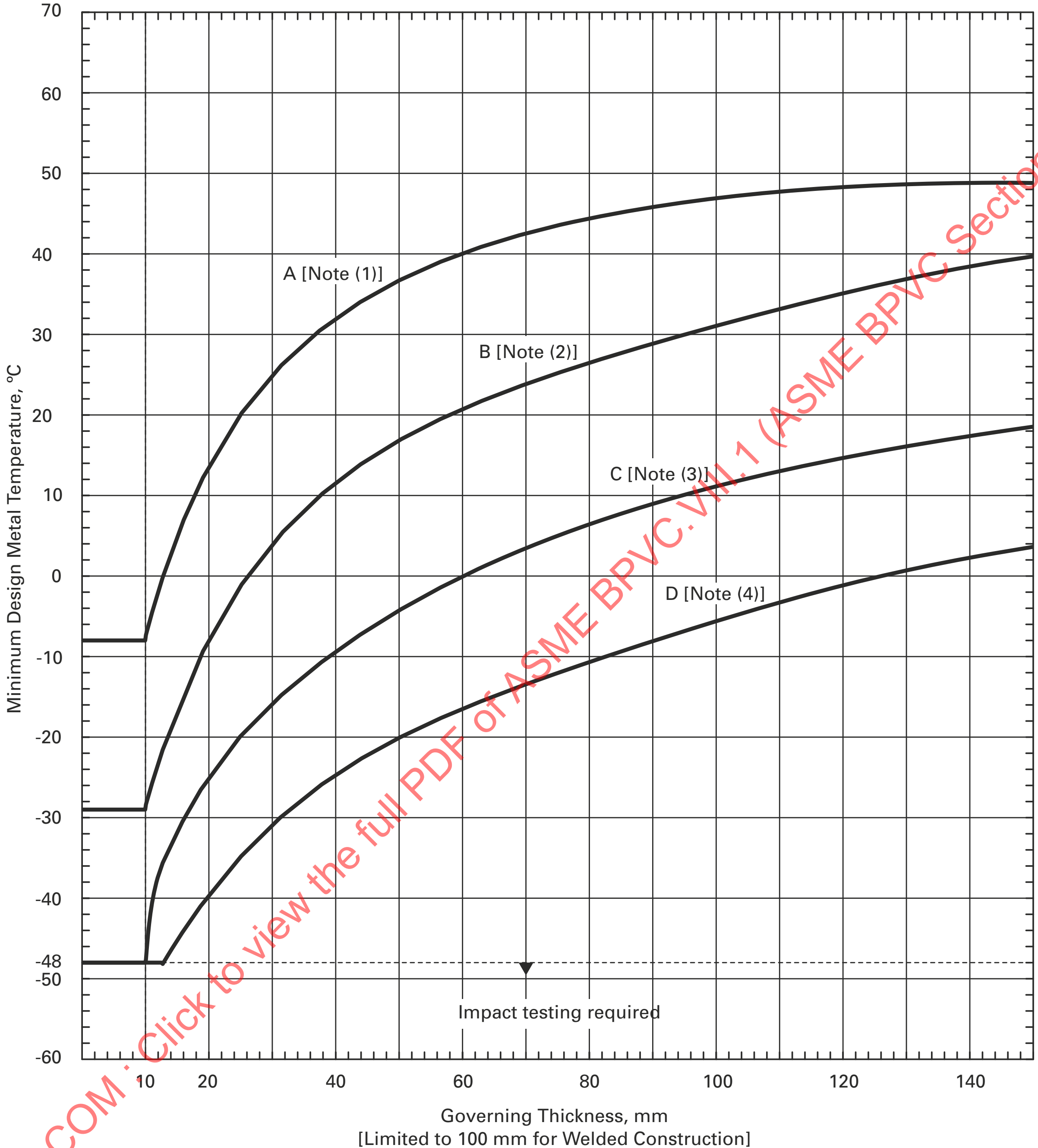
(b) all materials listed in Notes 2(a) and 2(c) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below

(4) Curve D applies to the following:

SA-203
SA-299 if normalized
SA-508 Grade 1
SA-516 if normalized or quenched and tempered
SA-524 Classes 1 and 2
SA-537 Classes 1, 2, and 3
SA-612 if normalized
SA-662 if normalized
SA-738 Grade A
SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −20°F (−29°C)
SA-738 Grade B not colder than −20°F (−29°C)
SA/AS 1548 Grades PT430N and PT460N
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH if normalized
SA/EN 10028-3 Grade P275NH
SA/GB 713 Grade Q345R if normalized

(25)

Figure UCS-66M
Impact Test Exemption Curves



GENERAL NOTES:
(a) Tabular values for this figure are provided in Table UCS-66.
(b) See UCS-66(a).
(c) For bolting and nuts, the following impact test exemption temperatures shall apply:

Bolting

Spec. No.	Grade	Diameter, in. (mm)	Impact Test Exemption Temperature, °F (°C)
SA-193	B5	Up to 4 (100), incl.	−20 (−29)
SA-193	B7	Up to $2^1/_2$ in. (64), incl.	−55 (−48)
SA-193	...	Over $2^1/_2$ (64) to 7 (175), incl.	−40 (−40)
SA-193	B7M	Up to $2^1/_2$ (64), incl.	−55 (−48)

Figure UCS-66M
Impact Test Exemption Curves (Cont'd)

GENERAL NOTES (CONT'D):

Table continued

Bolting			
Spec. No.	**Grade**	**Diameter, in. (mm)**	**Impact Test Exemption Temperature, °F (°C)**
SA-193	B16	Up to $2^1/_2$ (64), incl.	−55 (−48)
SA-193	...	Over $2^1/_2$ (64) to 7 (175), incl.	−20 (−29)
SA-307	B	All	−20 (−29)
SA-320	L7, L7A, L7M	Up to $2^1/_2$ (64), incl.	See Figure UG-84.5-1M, General Note (c)
SA-320	L43	Up to 1 (25), incl.	See Figure UG-84.5-1M, General Note (c)
SA-325	1	$^1/_2$ (13) to $1^1/_2$ (38)	−20 (−29)
SA-354	BC	Up to 4 (100), incl.	0 (−18)
SA-354	BD	Up to 4 (100), incl.	+20 (−7)
SA-437	B4B, B4C	All diameters	See Figure UG-84.5-1M, General Note (c)
SA-449	...	Up to 3 (75), incl.	−20 (−29)
SA-540	B21 Cl. All	All	Impact test required
SA-540	B22 Cl. 3	Up to 4 (100), incl.	Impact test required
SA-540	B23 Cl. 1, 2	All	Impact test required
SA-540	B23 Cl. 3, 4	Up to 6 (150), incl.	See Figure UG-84.5-1M, General Note (c)
SA-540	B23 Cl. 3, 4	Over 6 (150) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B23 Cl. 5	Up to 8 (200), incl.	See Figure UG-84.5-1M, General Note (c)
SA-540	B23 Cl. 5	Over 8 (200) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B24 Cl. 1	Up to 6 (150), incl.	See Figure UG-84.5-1M, General Note (c)
SA-540	B24 Cl. 1	Over 6 (150) to 8 (200), incl.	Impact test required
SA-540	B24 Cl. 2	Up to 7 (175), incl.	See Figure UG-84.5-1M, General Note (c)
SA-540	B24 Cl. 2	Over 7 (175) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B24 Cl. 3, 4	Up to 8 (200), incl.	See Figure UG-84.5-1M, General Note (c)
SA-540	B24 Cl. 3, 4	Over 8 (200) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B24 Cl. 5	Up to $9^1/_2$ (240), incl.	See Figure UG-84.5-1M, General Note (c)
SA-540	B24V Cl. 3	All	See Figure UG-84.5-1M, General Note (c)

Nuts		
Spec. No.	**Grade**	**Impact Test Exemption Temperature, °F (°C)**
SA-194	2, 2H, 2HM, 3, 4, 7, 7M, and 16	−55 (−48)
SA-540	B21/B22/B23/B24/B24V	−55 (−48)

(d) When no class or grade is shown, all classes or grades are included.

(e) The following shall apply to all material assignment notes:

(1) Cooling rates faster than those obtained by cooling in air, followed by tempering, as permitted by the material specification, are considered to be equivalent to normalizing or normalizing and tempering heat treatments.

(2) Fine grain practice is defined as the procedure necessary to obtain a fine austenitic grain size as described in SA-20.

(3) Normalized rolling condition is not considered as being equivalent to normalizing.

(f) Castings not listed in Notes (1) and (2) below shall be impact tested.

NOTES:

(1) Curve A applies to the following:

(a) all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below

(b) SA-216 Grades WCB and WCC if normalized and tempered or water-quenched and tempered; SA-217 Grade WC6 if normalized and tempered or water-quenched and tempered

(c) A/SA-105 forged flanges supplied in the as-forged condition

(d) SA/IS 2062 Grades E250A, E250BR, E250B0, and E250C supplied in the normalized rolling condition.

(2) Curve B applies to the following:

(a) see below:

A/SA-105 forged flanges produced to fine grain practice and normalized, normalized and tempered, or quenched and tempered after forging

SA-216 Grade WCA if normalized and tempered or water-quenched and tempered

SA-216 Grades WCB and WCC for thicknesses not exceeding 2 in. (50 mm) , if produced to fine grain practice and water-quenched and tempered

SA-217 Grade WC9 if normalized and tempered

Figure UCS-66M
Impact Test Exemption Curves (Cont'd)

NOTES (CONT'D):

SA-285 Grades A and B
SA-299
SA-414 Grade A
SA-515 Grade 60
SA-516 Grades 65 and 70 if not normalized
SA-612 if not normalized
SA-662 Grade B if not normalized
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH as rolled
SA/AS 1548 Grades PT430NR and PT460NR
SA/GB 713 Grade Q345R if not normalized

(b) except for cast steels, all materials of Curve A, if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed in Curves C and D below

(c) all pipe, fittings, forgings and tubing not listed for Curves C and D below

(d) parts permitted under UG-11 even when fabricated from plate that otherwise would be assigned to a different curve

(3) Curve C applies to the following:

(a) see below:

SA-182 Grades F21 and F22 if normalized and tempered
SA-302 Grades C and D
SA-336 F21 and F22 if normalized and tempered, or liquid quenched and tempered
SA-387 Grades 21 and 22 if normalized and tempered, or liquid quenched and tempered
SA-516 Grades 55 and 60 if not normalized
SA-533 Types B and C Class 1
SA-662 Grade A
SA/EN 10028-2 Grade 10CrMo9–10 if normalized and tempered

(b) all materials listed in Notes 2 (a) and 2 (c) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below

(4) Curve D applies to the following:

SA-203
SA-299 if normalized
SA-508 Grade 1
SA-516 if normalized or quenched and tempered
SA-524 Classes 1 and 2
SA-537 Classes 1, 2, and 3
SA-612 if normalized
SA-662 if normalized
SA-738 Grade A
SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −20°F (−29°C)
SA-738 Grade B not colder than −20°F (−29°C)
SA/AS 1548 Grades PT430N and PT460N
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH if normalized
SA/EN 10028-3 Grade P275NH
SA/GB 713 Grade Q345R if normalized

temperatures shall be used as the permissible minimum design metal temperature of the welded assembly. [See Figure UCS-66.3, sketch (b).]

(-5) if the governing thickness at any welded joint exceeds 4 in. (100 mm) and the minimum design metal temperature is colder than 120°F (50°C), impact tested material shall be used.

(-b) The governing thickness of a casting shall be its largest nominal thickness.

(-c) The governing thickness of flat nonwelded parts, such as bolted flanges, tubesheets, and flat heads, is the flat component thickness divided by 4.

(-d) The governing thickness of a nonwelded dished head [see Figure 1-6, sketch (c)] is the greater of the flat flange thickness divided by 4 or the minimum thickness of the dished portion.

(-e) If the governing thickness of the nonwelded part exceeds 6 in. (150 mm) and the minimum design metal temperature is colder than 120°F (50°C), impact tested material shall be used.

(2) Examples of the governing thickness for some typical vessel details are shown in Figure UCS-66.3.

NOTE: The use of provisions in UCS-66 which waive the requirements for impact testing does not provide assurance that all test results for these materials would satisfy the impact energy requirements of UG-84 if tested.

(b) When the coincident ratio defined in Figure UCS-66.1 (Figure UCS-66.1M) is less than one, Figure UCS-66.1 (Figure UCS-66.1M) provides a basis for the use of components made of Part UCS materials to have a colder MDMT than that derived from (a) above without impact testing. Use of Figure UCS-66.1 (Figure UCS-66.1M) is not permitted for bolts and nuts. For pressure vessel attachments that are exposed to tensile stresses from internal pressure (e.g., nozzle reinforcement pads, horizontal vessel saddle attachments, and stiffening rings), the coincident ratio shall be that of the shell or head to which each component is attached.

(1) See below.

(-a) For such components, and for a MDMT of −55°F (−48°C) and warmer, the MDMT without impact testing determined in (a) above for the given material and thickness may be reduced as determined from Figure UCS-66.2. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required.

(-b) Figure UCS-66.1 (Figure UCS-66.1M) may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges. The MDMT of these components without impact testing as determined in (a) or (c) may be reduced as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required, provided the MDMT is not colder than −55°F (−48°C).

(-c) In lieu of using (-b) above, the MDMT determined in (a) may be reduced for a flange attached by welding, by the same reduction as determined in (-a) above for the neck or shell to which the flange is attached.

NOTE: The gasket seating condition need not be considered when determining the temperature reduction for flanges.

(-d) Longitudinal stress in the vessel due to net-section bending that results in general primary membrane tensile stress (e.g., due to wind or earthquake in a vertical vessel, at mid-span and in the plane of the saddles of a saddle-supported horizontal vessel) shall be considered when calculating the coincident ratio in Figure UCS-66.2, Step 3 [see Figure UCS-66.2, Note (2)].

(2) For minimum design metal temperatures colder than −55°F (−48°C), impact testing is required for all materials, except as allowed in (3) below and in UCS-68.2.

(3) When the minimum design metal temperature is colder than −55°F (−48°C) and no colder than −155°F (−105°C), and the coincident ratio defined in Figure UCS-66.1 (Figure UCS-66.1M) is less than or equal to 0.35, impact testing is not required.

(c) Impact testing is not required for the following types of ferritic steel flanges:

(1) ASME B16.5, ASME B16.47, and long weld neck forged flanges:

(-a) when produced to fine-grain practice and supplied in the heat-treated condition (normalized, normalized and tempered, or quenched and tempered after forging) and used at design temperatures not colder than −20°F (−29°C). A certification statement on a Material Test Report or certificate of compliance attesting to production to fine grain practice is sufficient.

(-b) when supplied in the as-forged condition and used at design temperatures not colder than 0°F (−18°C).

Long weld neck flanges are defined as forged nozzles meeting the dimensional requirements of a flanged fitting given in ASME B16.5 but having a straight hub/neck. The inside diameter of the neck shall not be less than the nominal pipe size of the flange, and the outside diameter of the hub/neck shall not exceed the hub diameter specified in ASME B16.5.

(2) SA-216 GR WCB split loose cast flanges used at minimum design metal temperatures not colder than −20°F (−29°C) when

(-a) their outside diameter and bolting dimensions comply with either ASME B16.5 Class 150 or Class 300

(-b) the flange thickness is not greater than either ASME B16.5 Class 150 or Class 300, respectively

(d) No impact testing is required for Part UCS materials 0.10 in. (2.5 mm) in thickness and thinner, but such exempted Part UCS materials shall not be used at design metal temperatures colder than −55°F (−48°C). For vessels or components made from NPS 4 (DN 100) or smaller

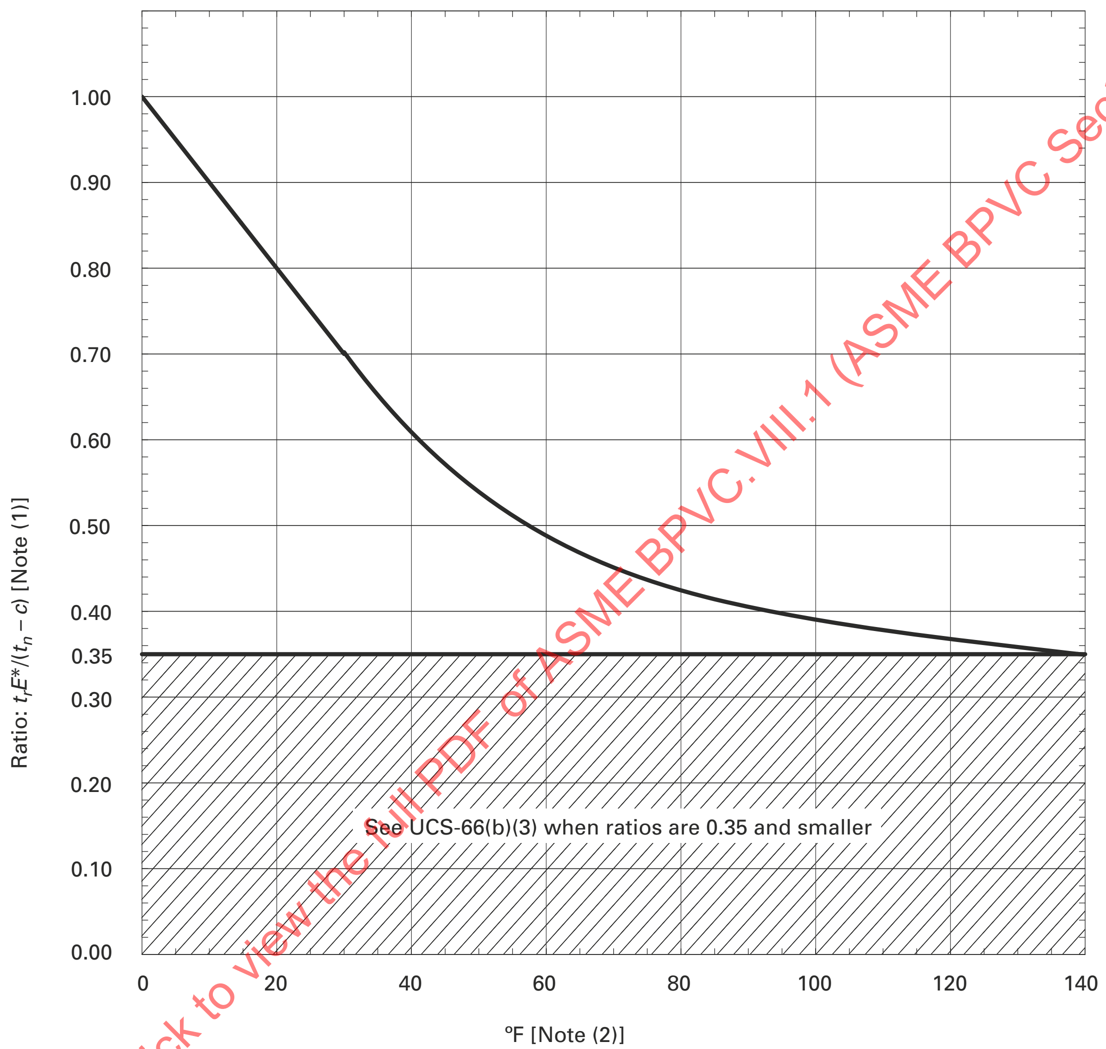
Table UCS-66
Tabular Values for Figures UCS-66 and UCS-66M

Customary Units					SI Units				
Thickness, in.	Curve A, °F	Curve B, °F	Curve C, °F	Curve D, °F	Thickness, mm	Curve A, °C	Curve B, °C	Curve C, °C	Curve D, °C
0.25	18	−20	−55	−55	6.4	−8	−29	−48	−48
0.3125	18	−20	−55	−55	7.9	−8	−29	−48	−48
0.375	18	−20	−55	−55	9.5	−8	−29	−48	−48
0.4375	25	−13	−40	−55	11.1	−4	−25	−40	−48
0.5	32	−7	−34	−55	12.7	0	−22	−37	−48
0.5625	37	−1	−26	−51	14.3	3	−18	−32	−46
0.625	43	5	−22	−48	15.9	6	−15	−30	−44
0.6875	48	10	−18	−45	17.5	9	−12	−28	−43
0.75	53	15	−15	−42	19.1	12	−9	−26	−41
0.8125	57	19	−12	−38	20.6	14	−7	−24	−39
0.875	61	23	−9	−36	22.2	16	−5	−23	−38
0.9375	65	27	−6	−33	23.8	18	−3	−21	−36
1.0	68	31	−3	−30	25.4	20	−1	−19	−35
1.0625	72	34	−1	−28	27.0	22	1	−18	−33
1.125	75	37	2	−26	28.6	24	3	−17	−32
1.1875	77	40	2	−23	30.2	25	4	−17	−31
1.25	80	43	6	−21	31.8	27	6	−14	−30
1.3125	82	45	8	−19	33.3	28	7	−13	−28
1.375	84	47	10	−18	34.9	29	8	−12	−28
1.4375	86	49	12	−16	36.5	30	9	−11	−27
1.5	88	51	14	−14	38.1	31	11	−10	−26
1.5625	90	53	16	−13	39.7	32	12	−9	−25
1.625	92	55	17	−11	41.3	33	13	−8	−24
1.6875	93	57	19	−10	42.9	34	14	−7	−23
1.75	94	58	20	−8	44.5	34	14	−7	−22
1.8125	96	59	22	−7	46.0	36	15	−6	−22
1.875	97	61	23	−6	47.6	36	16	−5	−21
1.9375	98	62	24	−5	49.2	37	17	−4	−21
2.0	99	63	26	−4	50.8	37	17	−3	−20
2.0625	100	64	27	−3	52.4	38	18	−3	−19
2.125	101	65	28	−2	54.0	38	18	−2	−19
2.1875	102	66	29	−1	55.6	39	19	−2	−18
2.25	102	67	30	0	57.2	39	19	−1	−18
2.3125	103	68	31	1	58.7	39	20	−1	−17
2.375	104	69	32	2	60.3	40	21	0	−17
2.4375	105	70	33	3	61.9	41	21	1	−16
2.5	105	71	34	4	63.5	41	22	1	−16
2.5625	106	71	35	5	65.1	41	22	2	−15
2.625	107	73	36	6	66.7	42	23	2	−14
2.6875	107	73	37	7	68.3	42	23	3	−14
2.75	108	74	38	8	69.9	42	23	3	−13
2.8125	108	75	39	8	71.4	42	24	4	−13
2.875	109	76	40	9	73.0	43	24	4	−13
2.9375	109	77	40	10	74.6	43	25	5	−12
3.0	110	77	41	11	76.2	43	26	5	−12
3.0625	111	78	42	12	77.8	44	26	6	−11
3.125	111	79	43	12	79.4	44	26	6	−11
3.1875	112	80	44	13	81.0	44	27	7	−11
3.25	112	80	44	14	82.6	44	27	7	−10
3.3125	113	81	45	15	84.1	45	27	7	−9
3.375	113	82	46	15	85.7	45	28	8	−9
3.4375	114	83	46	16	87.3	46	28	8	−9

Table UCS-66
Tabular Values for Figures UCS-66 and UCS-66M (Cont'd)

Customary Units					SI Units				
Thickness, in.	Curve A, °F	Curve B, °F	Curve C, °F	Curve D, °F	Thickness, mm	Curve A, °C	Curve B, °C	Curve C, °C	Curve D, °C
3.5	114	83	47	17	88.9	46	28	8	−8
3.5625	114	84	48	17	90.5	46	29	9	−8
3.625	115	85	49	18	92.1	46	29	9	−7
3.6875	115	85	49	19	93.7	46	29	9	−7
3.75	116	86	50	20	95.3	47	30	10	−7
3.8125	116	87	51	21	96.8	47	31	11	−6
3.875	116	88	51	21	98.4	47	31	11	−6
3.9375	117	88	52	22	100.0	47	32	11	−6
4.0	117	89	52	23	101.6	47	32	11	−5
4.0625	117	90	53	23	103.0	47	32	12	−5
4.125	118	90	54	24	105.0	48	32	12	−4
4.1875	118	91	54	25	106.0	48	33	12	−4
4.25	118	91	55	25	108.0	48	33	12	−4
4.3125	118	92	55	26	110.0	48	33	12	−3
4.375	119	93	56	27	111.0	49	34	13	−3
4.4375	119	93	56	27	113.0	49	34	13	−3
4.5	119	94	57	28	114.0	49	34	13	−2
4.5625	119	94	57	29	115.0	49	34	13	−2
4.625	119	95	58	29	117.0	49	35	14	−2
4.6875	119	95	58	30	118.0	49	35	14	−1
4.75	119	96	59	30	119.0	49	35	14	−1
4.8125	119	96	59	31	120.0	49	35	14	−1
4.875	119	97	60	31	121.0	49	36	15	−1
4.9375	119	97	60	32	122.0	49	36	15	0
5	119	97	60	32	123.0	49	36	15	0
5.0625	119	98	61	33	124.0	49	36	15	0
5.125	119	98	61	33	125.0	49	36	15	0
5.1875	119	98	62	34	126.0	49	36	16	1
5.25	119	99	62	34	127.0	49	37	16	1
5.3125	119	99	62	35	128.0	49	37	16	1
5.375	119	100	63	35	129.0	49	37	16	1
5.4375	119	100	63	36	130.0	49	37	16	2
5.5	119	100	63	36	131.0	49	37	16	2
5.5625	119	101	64	36	132.0	49	38	17	2
5.625	119	101	64	37	133.0	49	38	17	2
5.6875	119	102	64	37	134.0	49	38	17	2
5.75	120	102	65	38	135.0	50	38	17	3
5.8125	120	103	65	38	136.0	50	39	17	3
5.875	120	103	66	38	137.0	50	39	18	3
5.9375	120	104	66	39	138.0	50	39	18	3
6.0	120	104	66	39	139.0	50	39	18	3

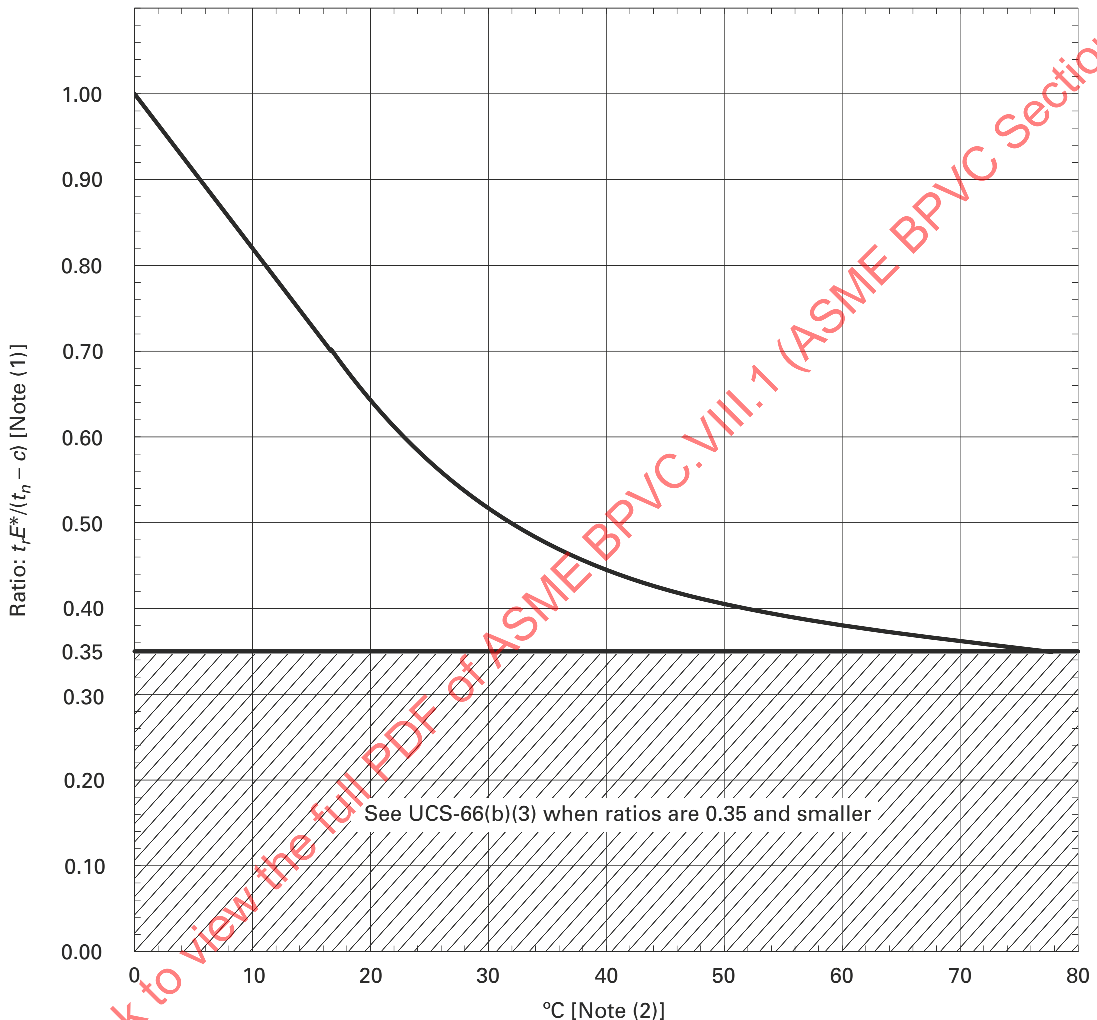
Figure UCS-66.1
Reduction in Minimum Design Metal Temperature Without Impact Testing



c = corrosion allowance, in.
E^* = as defined in Figure UCS-66.2, Note (3)
t_n = nominal thickness of the component under consideration before corrosion allowance is deducted, in.
t_r = required thickness of the component under consideration in the corroded condition for all applicable loadings [see Figure UCS-66.2, Note (2)], based on the applicable joint efficiency E [see Figure UCS-66.2, Note (3)], in.

NOTES:
(1) *Alternative Ratio* = $S^* E^*$ divided by the product of the maximum allowable stress value from Table UCS-23 times E, where S^* is the applied general primary membrane tensile stress and E and E^* are as defined in Figure UCS-66.2, Note (3)
(2) See UCS-66(b).

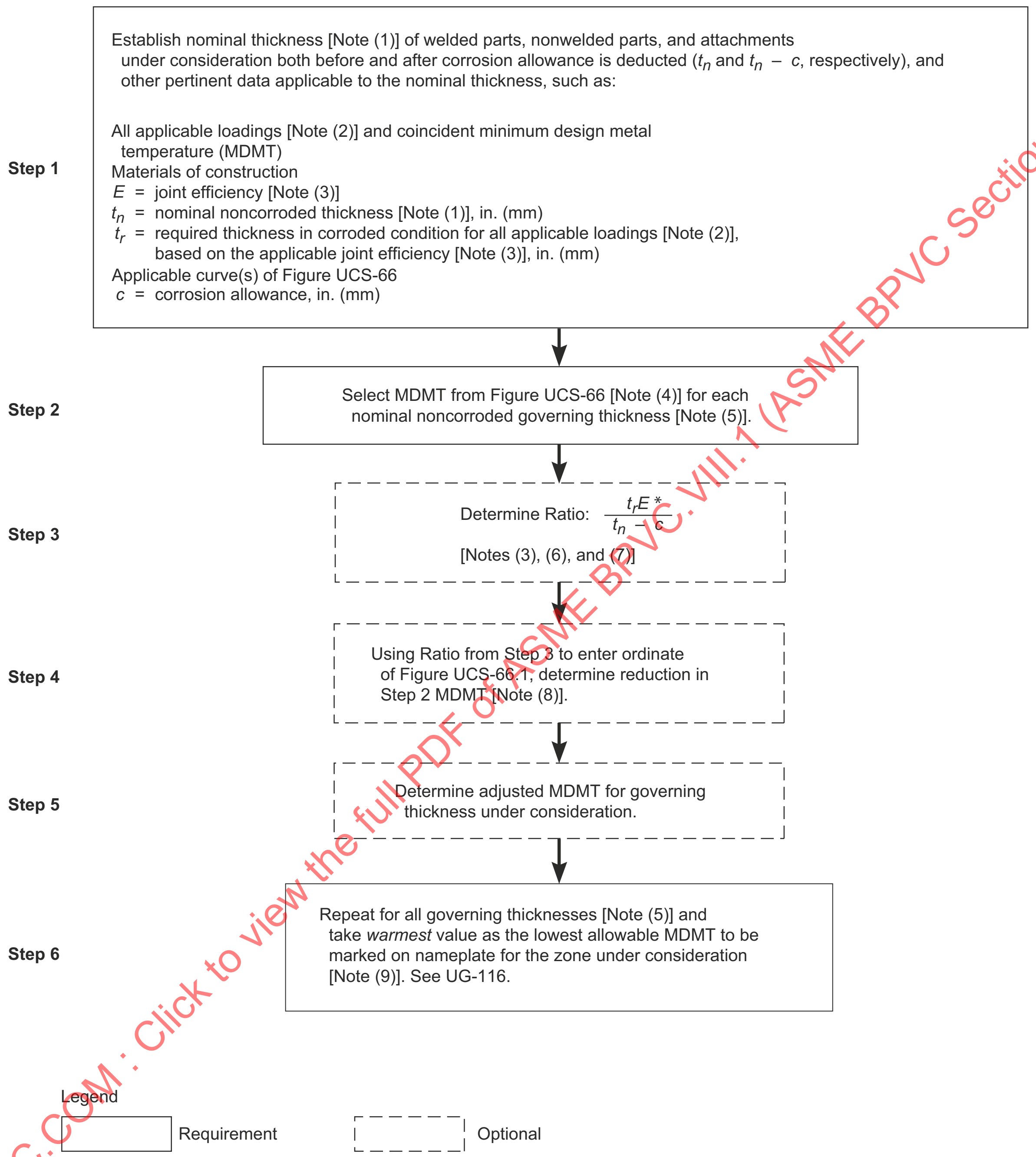
Figure UCS-66.1M
Reduction in Minimum Design Metal Temperature Without Impact Testing



c = corrosion allowance, mm
E^* = as defined in Figure UCS-66.2, Note (3)
t_n = nominal thickness of the component under consideration before corrosion allowance is deducted, mm
t_r = required thickness of the component under consideration in the corroded condition for all applicable loadings [see Figure UCS-66.2, Note (2)], based on the applicable joint efficiency E [see Figure UCS-66.2, Note (3)], mm

NOTES:
(1) *Alternative Ratio* = $S^* E^*$ divided by the product of the maximum allowable stress value from Table UCS-23 times E, where S^* is the applied general primary membrane tensile stress and E and E^* are as defined in Figure UCS-66.2, Note (3)
(2) See UCS-66(b).

Figure UCS-66.2
Diagram of UCS-66 Rules for Determining Lowest Minimum Design Metal Temperature (MDMT) Without Impact Testing



NOTES:

(1) For pipe where a mill undertolerance is allowed by the material specification, the thickness after mill undertolerance has been deducted shall be taken as the noncorroded nominal thickness t_n for determination of the MDMT to be stamped on the nameplate. Likewise, for formed heads, the minimum specified thickness after forming shall be used as t_n.

(2) Loadings, including those listed in UG-22, which result in general primary membrane tensile stress at the coincident MDMT.

(3) E is the joint efficiency (see Table UW-12) used in the calculation of t_r; E^* has a value equal to E except that E^* shall not be less than 0.80. For castings, use quality factor or joint efficiency, E, whichever governs design.

(4) The construction of Figure UCS-66 (Figure UCS-66M) is such that the MDMT so selected is considered to occur coincidentally with an applied general primary membrane tensile stress at the maximum allowable stress value in tension from Section II, Part D, Subpart 1, Table 1A. Tabular values for Figure UCS-66 (Figure UCS-66M) are shown in Table UCS-66.

Figure UCS-66.2
Diagram of UCS-66 Rules for Determining Lowest Minimum Design Metal Temperature (MDMT) Without Impact Testing (Cont'd)

NOTES (CONT'D):
(5) See UCS-66(a)(1)(-a), (a)(1)(-b), and (a)(1)(-c) for definitions of governing thickness.
(6) Alternatively, a Ratio of S^*E^* divided by the product of the maximum allowable stress value in tension from Section II, Part D, Subpart 1, Table 1A times E may be used, where S^* is the applied general primary membrane tensile stress and E and E^* are as defined in Note (3).
(7) For UCS-66(b)(1)(-b) and UCS-66(i)(2), a ratio of the maximum design pressure at the MDMT to the maximum allowable pressure (MAP) at the MDMT shall be used. The MAP is defined as the highest permissible pressure as determined by the design equations for a component using the nominal thickness less corrosion allowance and the maximum allowable stress value from the Section II, Part D, Subpart 1, Table 1A at the MDMT. For ferritic steel flanges defined in UCS-66(c), the flange rating at the warmer of the MDMT or 100°F (38°C) may be used as the MAP.
(8) For reductions in MDMT up to and including 40°F (22°C), the reduction can be determined by: reduction in MDMT = (1 − Ratio) 100°F (56°C).
(9) A colder MDMT may be obtained by selective use of impact tested materials as appropriate to the need (see UG-84). See also UCS-68(c).

tubes or pipe of P-No. 1 materials, the following exemptions from impact testing are also permitted as a function of the material specified minimum yield strength (SMYS) for metal temperatures of −155°F (−105°C) and warmer:

SMYS, ksi (MPa)	Thickness, in. (mm)
20 to 35 (140 to 240)	0.237 (6.0)
36 to 45 (250 to 310)	0.125 (3.2)
46 (320) and higher	0.10 (2.5)

(e) The material manufacturer's identification marking required by the material specification shall not be stamped on plate material less than $^1/_4$ in. (6 mm) in thickness unless the following requirements are met.

(1) The materials shall be limited to P-No. 1 Gr. Nos. 1 and 2.

(2) The minimum nominal plate thickness shall be $^3/_{16}$ in. (5 mm), or the minimum nominal pipe wall thickness shall be 0.154 in. (3.91 mm).

(3) The minimum design metal temperature shall be no colder than −20°F (−29°C).

(f) Materials, other than bolting materials, having a specified minimum yield strength greater than 65 ksi (450 MPa) shall be impact tested. However, they may be used at temperatures colder than the minimum design metal temperature as limited in (1) and (2) below.

(1) When the coincident ratio defined in Figure UCS-66.1 (Figure UCS-66.1M) is 0.35 or less, the corresponding minimum design metal temperature shall not be colder than −155°F (−104°C).

(2) When the coincident ratio defined in Figure UCS-66.1 (Figure UCS-66.1M) is greater than 0.35, the corresponding minimum design metal temperature shall not be colder than the impact test temperature less the allowable temperature reduction permitted in Figure UCS-66.1 (Figure UCS-66.1M) and shall in no case be colder than −155°F (−104°C).

(g) Materials produced and impact tested in accordance with the requirements of the specifications listed in Figure UG-84.5-1 (Figure UG-84.5-1M), General Note (c), are exempt from impact testing by the rules of this Division at minimum design metal temperatures not more than 5°F (3°C) colder than the test temperature required by the specification.

(h) No impact testing is required for metal backing strips which remain in place made of materials assigned to Curve A of Figure UCS-66 (Figure UCS-66M) in thicknesses not exceeding $^1/_4$ in. (6 mm) when the minimum design metal temperature is −20°F (−29°C) or warmer.

(i) For components made of Part UCS materials that are impact tested, Figure UCS-66.1 (Figure UCS-66.1M) provides a basis for the use of these components at an MDMT colder than the impact test temperature. For pressure vessel attachments that are exposed to tensile stresses from internal pressure (e.g., nozzle reinforcement pads, horizontal vessel saddle attachments, and stiffening rings), the coincident ratio shall be that of the shell or head to which each component is attached.

(1) For such components, the MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Figure UCS-66.2.

(2) Figure UCS-66.1 (Figure UCS-66.1M) may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges. The MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT.

(3) In lieu of using (2) above, the MDMT for a flange attached by welding shall not be colder than the impact test temperature less the allowable temperature reduction as determined in (1) above for the neck or shell to which the flange is attached.

(4) The requirements of (b)(1)(-d) shall be met.

Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66

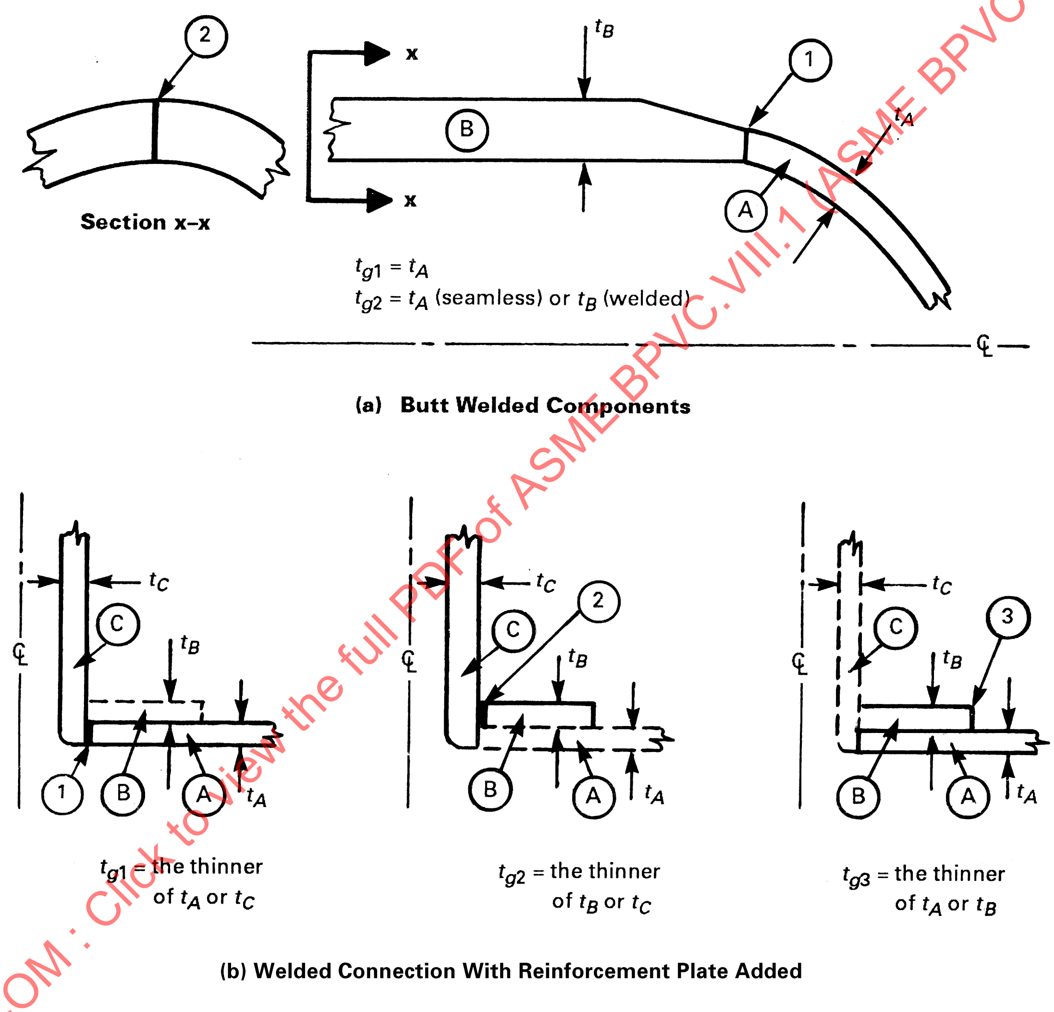
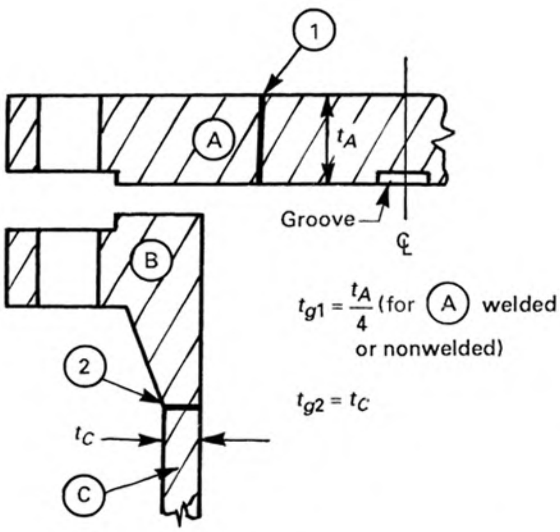
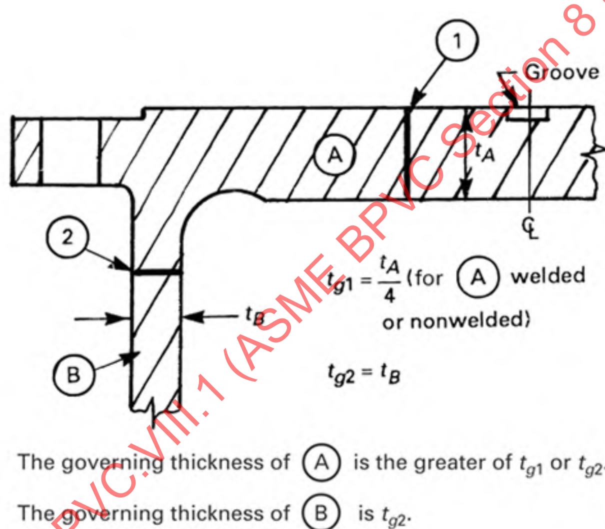


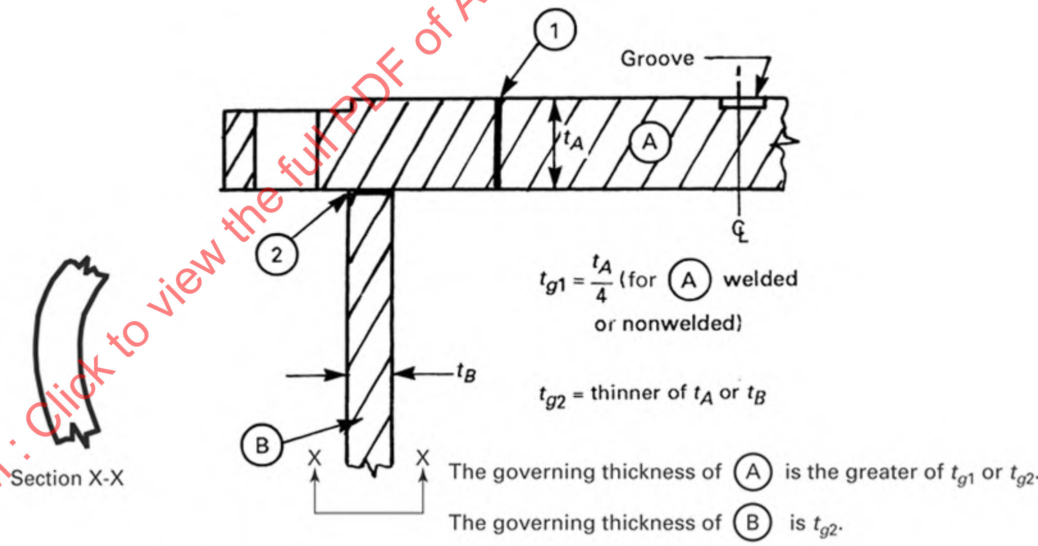
Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66 (Cont'd)



(c) Bolted Flat Head or Tubesheet and Flange

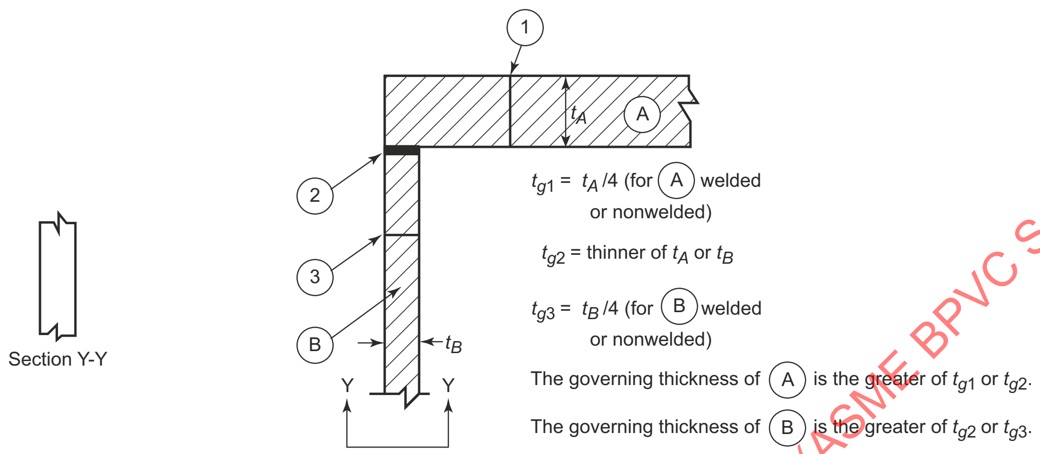


(d) Integral Flat Head or Tubesheet

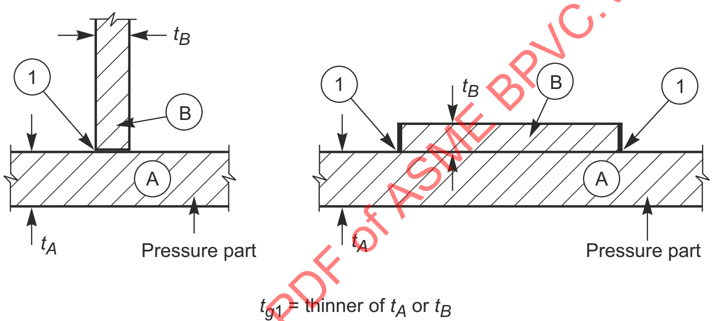


(e) Flat Head or Tubesheet Forming a Corner Joint With Cylinder

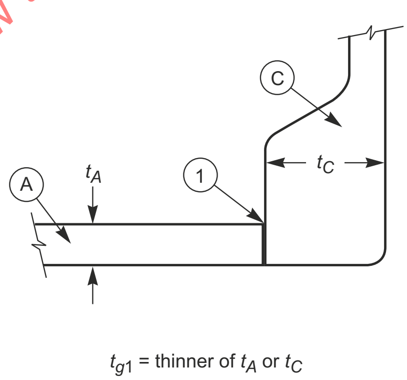
Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66 (Cont'd)



(f) Two Flat Plates With a Corner Joint



(g) Welded Attachments as Defined in UCS-66(a)



(h) Integrally Reinforced Welded Connection

GENERAL NOTES:

(a) Using t_{g1}, t_{g2}, and t_{g3}, determine the warmest MDMT and use that as the permissible MDMT for the welded assembly.

(b) t_g = governing thickness of the welded joint as defined in UCS-66.

(5) The MDMT adjustment as determined in (1) above may be used for impact tested welding procedures or production welds.

(6) The MDMT for the component shall not be colder than −155°F (−105°C).

(j) When the base metal is exempt from impact testing by (g) above or by Figure UCS-66 (Figure UCS-66M), Curve C or Curve D, −20°F (−29°C) is the coldest MDMT to be assigned for welded components that do not meet the requirements of UCS-67.

(25) ## UCS-67 IMPACT TESTS OF WELDING PROCEDURES

UCS-67.1 The MDMTs referenced in Table UCS-67.2-1 shall be one of the following:

(a) the MDMT stamped on the nameplate

(b) the exemption temperature obtained before applying any additional exemption temperature reductions permitted by UCS-66(b) or UCS-68.2

UCS-67.2 Unless otherwise exempted in UG-20(f), UCS-66, and UCS-68, a Welding Procedure Specification (WPS) to be used in production welding shall meet the requirements of Table UCS-67.2-1 for exemption or qualification with impact testing of the weld metal and heat-affected zones (HAZs) in accordance with UG-84.

(25) ## UCS-68 LOW TEMPERATURE SERVICE REQUIREMENTS

UCS-68.1 Weld Joint Types and Additional PWHT Requirements. The following additional requirements apply when the specified MDMT is colder than −55°F (−48°C) and the coincident ratio as defined in Figure UCS-66.1 (Figure UCS-66.1M) is 0.35 or greater. No provisions of this paragraph waive other requirements of this Division, such as UW-2(a), UW-2(d), UW-10, and UCS-56.

(a) Weld joints shall comply with UW-2(b).

(b) PWHT in accordance with the requirements of UW-40 is mandatory for welded joints unless exempted in (c).

(c) PWHT requirement in (b) does not apply when the following conditions are met:

(1) Vessel and vessel parts are fabricated of P-No. 1 materials that are impact tested at the specified MDMT or colder in accordance with UG-84.

(2) The minimum average energy requirement for base metals and weldments that are exempt from PWHT in (1) shall be 25 ft-lb (34 J) in lieu of the values shown in Figure UG-84.1 (Figure UG-84.1M).

(3) Welded joints shall be one of the following:

(-a) Type 1, Category A and B welded joints except for cone-to-cylinder junctions. Type 1, Category A and B joints attaching sections of unequal thickness shall have a transition with a slope not exceeding 3:1.

(-b) fillet welds having leg dimensions not exceeding $^3/_8$ in. (10 mm) attaching lightly loaded attachments, provided the attachment material and the attachment weld meet requirements of UCS-66 and UCS-67. A “lightly loaded attachment” is an attachment for which the stress in the attachment weld does not exceed 25% of the allowable stress.

(-c) seal welds as defined in UW-20.2(c).

(4) Welded joints described in (3)(-a) shall be 100% radiographed.

Table UCS-67.2-1
Requirement and Exemption of WPS Impact Testing Qualification (25)

Use of Filler Metal (With or Without)	MDMT (See UCS-67.1)	Individual Weld Pass Thickness	Base Metal Impact Testing Required or Exempt	WPS Qualification With Impact Testing
With or without	Any	Any	Required (either component)	Required
With or without	Colder than −55°F (−48°C)	Any	Exempt per UCS-66(g)	
Without	Any	>$^1/_2$ in. (>13 mm)	Regardless of base metal impact testing requirements	
Without	Colder than 50°F (10°C)	>$^5/_{16}$ in (>8 mm)		
With	Colder than 70°F (21°C)	>$^1/_2$ in. (>13 mm)		
With	Colder than −20°F (−29°C) but no colder than −55°F (−48°C)	>$^1/_4$ in. (>6 mm) [Note (1)]	Exempt per UCS-66(g) or Figure UCS-66, Curve C or Curve D	
With	Colder than −20°F (−29°C) but no colder than −55°F (−48°C)	≤$^1/_4$ in. (≤6 mm) [Note (2)]	Exempt per UCS-66(g) or Figure UCS-66, Curve C or Curve D	Not required

NOTES:

(1) Not required when the filler metal is qualified per Note (2), or when the filler metal is not qualified per Note (2) regardless of any weld pass thickness.

(2) Not required when each heat of filler metal, or the combination of a filler metal heat and a flux lot, is classified by its manufacturer with impact testing in accordance with the applicable SFA specification at a test temperature not warmer than the MDMT. Additional impact testing beyond the requirements of the SFA specification may be performed by the filler metal or flux manufacturer to expand their classifications for a broader range of temperatures.

(5) Fillet and seal welds described in (3)(-b) and (3)(-c) shall be examined by one of the following methods:

(-a) magnetic particle examination in accordance with Mandatory Appendix 6

(-b) liquid penetrant examination in accordance with Mandatory Appendix 8

UCS-68.2 Impact Testing Exemption Temperature Reduction With PWHT.

(a) If PWHT is applied to a pressure-retaining weld when it is not otherwise required by this Division, the impact testing exemption temperature from Figure UCS-66 (Figure UCS-66M) for P-No. 1 materials may be reduced by 30°F (17°C).

(b) The impact testing exemption temperature resulting from (a) may be colder than −55°F (−48°C) when the PWHT exemption in UCS-68.1(c) is applicable.

UCS-68.3 Allowable Stress Values. The allowable stress values to be used in design calculations for service at the MDMT shall not exceed those in Section II, Part D, Subpart 1, Table 3 for bolting, and Table 1A for other materials at 100°F (38°C).

FABRICATION

(25) UCS-75 GENERAL

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of carbon and low alloy steel and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsections B and D.

UCS-79 FORMING PRESSURE PARTS

(a) The following provisions shall apply in addition to the general rules for forming given in UG-79.

(b) Carbon and low alloy steel plates shall not be formed cold by blows.

(c) Carbon and low alloy steel plates may be formed by blows at a forging temperature provided the blows do not objectionably deform the plate and it is subsequently postweld heat treated.

(d) Except as addressed in (e) and for materials exempted below, the cold-formed areas of vessel shell sections, heads, and other pressure parts shall be heat treated if the resulting extreme fiber elongation determined in accordance with Table UG-79-1 exceeds 5% from the supplied condition. Heat treatment shall be applied in accordance with UCS-56, except that alternative heating and cooling rates and hold times may be applied to formed pipe and tube having a nominal thickness of $\frac{1}{4}$ in. (6 mm) or less when the heat treatment method is demonstrated to achieve a thorough heating of the pipe or tube.

(1) Cold-formed and bent P-No. 1 pipe and tube material having a nominal thickness not greater than $\frac{3}{4}$ in. (19 mm) does not require post-forming heat treatment.

(2) For P-No. 1, Group Nos. 1 and 2 materials other than those addressed by (1), post-forming heat treatment is required when the extreme fiber elongation exceeds 40% or if the extreme fiber elongation exceeds 5% and any of the following conditions exist:

(-a) The vessel will contain lethal liquid or gaseous substances (see UW-2).

(-b) The material is not exempt from impact testing by the rules of this Division, or impact testing is required by the material specification.

(-c) The nominal thickness of the part before cold forming exceeds $\frac{5}{8}$ in. (16 mm).

(-d) The reduction by cold forming from the nominal thickness is more than 10% at any location where the extreme fiber elongation exceeds 5%.

(-e) The temperature of the material during forming is in the range of 250°F to 900°F (120°C to 480°C).

(3) Cold-formed or bent P-Nos. 3 through 5C pipe and tube materials having an outside diameter not greater than $4\frac{1}{2}$ in. (114 mm) and a nominal thickness not greater than $\frac{1}{2}$ in. (13 mm) do not require a post-forming heat treatment.

The extreme fiber elongation shall be determined by the equations in Table UG-79-1.

(e) Forming of Creep-Strength-Enhanced Ferritic Steels (P-No. 15E Materials). The cold-formed areas of vessel shell sections, heads, and other pressure boundary parts of the creep-strength-enhanced ferritic steels shall be heat treated as listed in Table UCS-79-1. Cold forming is defined as any forming that is performed at a temperature below 1,300°F (705°C) and produces permanent strain in the material. Hot forming is defined as any forming that is performed at or above a temperature of 1,300°F (705°C) and produces permanent strain in the material. Forming strains (extreme fiber elongations) shall be calculated using the equations of Table UG-79-1.

(1) When the forming strains cannot be calculated as shown in Table UG-79-1, the Manufacturer shall have the responsibility to determine the maximum forming strain.

(2) For cold-formed flares, swages, or upsets in tubing and pipe, normalizing and tempering in accordance with Note (1) of Table UCS-79-1 shall apply, regardless of the amount of strain.

(3) For any hot-formed product form, normalizing and tempering in accordance with Note (1) of Table UCS-79-1 shall apply, regardless of the amount of strain.

(f) When vessel shell sections, heads, and other pressure boundary parts of carbon and low alloy steel are cold formed by other than the Manufacturer of the vessel, the required certification for the part shall indicate if the part has been heat treated per the requirements of UCS-79.

Table UCS-79-1
Post-Cold-Forming Strain Limits and Heat Treatment Requirements for P-No. 15E Materials

Grade	UNS Number	Limitations in Lower Temperature Range					Limitations in Higher Temperature Range			Required Heat Treatment When Design Temperature and Forming Strain Limits Are Exceeded
		For Design Temperature				And Forming Strains	For Design Temperature Exceeding		And Forming Strains	
		Exceeding		But Less Than or Equal to						
		°F	°C	°F	°C		°F	°C		
91	K90901	1,000	540	1,115	600	>25%	1,115	600	>20%	Normalize and temper [Note (1)]
		1,000	540	1,115	600	>5 to ≤25%	1,115	600	>5 to ≤20%	Post-forming heat treatment [Note (2)], [Note (3)], and [Note (4)]

GENERAL NOTE: The limits shown are for cylinders formed from plates, spherical or dished heads formed from plate, and tube and pipe bends. The forming strain limits tabulated above shall be divided by 2 if the equation, from Table UG-79-1, for double-curvature products such as heads, is applied.

NOTES:
(1) Normalization and tempering shall be performed in accordance with the requirements of the base material specification and shall not be performed locally. Either the material shall be heat treated in its entirety, or the cold-strained area (including the transition to the unstrained portion) shall be cut away from the balance of the component and heat treated separately, or replaced.
(2) Post-forming heat treatments shall be performed at 1,350°F to 1,435°F (730°C to 780°C) for 1 hr/in. (1 h/25 mm) or 30 min, minimum. Alternatively, a normalization and temper in accordance with the requirements in the base metal specification may be performed.
(3) For materials with greater than 5% strain but less than or equal to 25% strain with design temperatures less than or equal to 1,115°F (600°C), if a portion of the component is heated above the heat treatment temperature allowed in [Note (2)], one of the following actions shall be performed:
(a) The component in its entirety shall be renormalized and tempered.
(b) The allowable stress shall be that for Grade 9 material (i.e., SA-213 T9, SA-335 P9, or equivalent product specification) at the design temperature, provided that portion of the component that was heated to a temperature exceeding the maximum holding temperature is subjected to a final heat treatment within the temperature range and for the time required in [Note (2)]. The use of this provision shall be noted on the Manufacturer's Data Report.
(4) If a longitudinal weld is made to a portion of the material that is cold strained, that portion shall be normalized and tempered, prior to or following welding. This normalizing and tempering shall not be performed locally.

(25) UCS-85 HEAT TREATMENT OF TEST SPECIMENS

The following additional provisions and exceptions shall apply to the general rules for heat treatment given in UG-85.

(a) As referenced in this paragraph, heat treatment includes all heat treatments applied to Part UCS materials except for

(1) local heating such as thermal cutting, preheating, welding, and torch brazing

(2) heating to temperatures below the lower transformation temperature of tubing and pipe for bending or sizing

(b) Mechanical property testing is required when materials are subjected to fabrication heat treatments at temperatures exceeding 900°F (480°C) except as modified by (c), (d), (e), (f), and (g). The test specimens shall be prepared and tested as follows:

(1) The kind and number of tests and acceptance criteria for the test results shall be those required by the material specification.

(2) The vessel Manufacturer shall verify the test specimens are heat treated to the same temperature, holding time, and cooling rates to be applied during fabrication, except as permitted in (e).

(3) The test specimens shall be heated to the specified temperature within ±15°F (±8°C).

(4) The total time at temperature shall be at least 80% of the total time at temperature to be applied during fabrication and may be performed in a single cycle.

(c) The following materials do not require the mechanical property testing described in (b) when heat treatment during fabrication is limited to PWHT at temperatures below the lower transformation temperature:

(1) nonwelded standard pressure parts described in UG-11(c) and UG-11(d)

(2) P-No. 1, Group Nos. 1 and 2 materials

(3) all carbon and low alloy steels used in the annealed condition as permitted by the material specification, except for SA-841

(d) Materials listed as P-No. 1, Group No. 3 or P-No. 3, Group No. 1 or No. 2 that are tested in accordance with (b) from test specimens subjected to the PWHT

requirements of Table UCS-56-1 or Table UCS-56-2 do not require retesting when subjected to the alternate PWHT conditions permitted by Table UCS-56-12.

(e) The simulation of cooling rates is not required for test specimens heat treated below the lower transformation temperature when removed from non-impact-tested materials not greater than 3 in. (75 mm) thick.

(f) The testing described in (b) is not required when

(1) the material is a nonwelded, normalized, P-No. 1, Gr. 1 material not thicker than $1^1/_2$ in. (38 mm) before forming, and the following conditions are met:

(-a) The material is subsequently cold formed and normalized or hot formed at a normalizing or hot-forming temperature within ±20°F (±11°C) of the normalizing temperature reported on the Material Test Report.

(-b) The normalizing or hot-forming temperature, holding time, and the type of cooling applied shall be documented by the manufacturer of the formed part as an addendum to the Material Test Report.

(2) a normalized material is formed and welded to create a component that receives a subsequent austenitizing heat treatment after welding and forming

(g) All heat treatments applied at temperatures preceding and colder than a final austenitizing heat treatment of a material are not required to be represented in the test specimens.

INSPECTION AND TESTS

UCS-90 GENERAL (25)

The provisions for inspection and testing in Subsections A, B, and D shall apply without supplement to vessels constructed of carbon and low alloy steels.

MARKING AND REPORTS

UCS-115 GENERAL

The provisions for marking and reports in , UG-115 through UG-120 shall apply without supplement to pressure vessels constructed of carbon and low alloy steels.

NONMANDATORY APPENDIX UCS-A

UCS-A-1 GENERAL

See Section II, Part D, Nonmandatory Appendix A, A-100.

UCS-A-2 CREEP–RUPTURE PROPERTIES OF CARBON STEELS

See Section II, Part D, Nonmandatory Appendix A, A-200.

UCS-A-3 VESSELS OPERATING AT TEMPERATURES COLDER THAN THE MDMT STAMPED ON THE NAMEPLATE

(a) Vessels or components may be operated at temperatures colder than the MDMT stamped on the nameplate, provided the provisions of UCS-66, UCS-67, and UCS-68 are met when using the reduced (colder) operating temperature as the MDMT, but in no case shall the operating temperature be colder than −155°F (−105°C).

(b) As an alternative to (a) above, for vessels or components whose thicknesses are based on pressure loading only, the coincident operating temperature may be as cold as the MDMT stamped on the nameplate less the allowable temperature reduction as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum pressure at the coincident operating temperature to the MAWP of the vessel at the stamped MDMT, but in no case shall the operating temperature be colder than −155°F (−105°C).

NOTE: One common usage of the exemptions in (a) and (b) is for vessels in which the internal pressure is dependent on the vapor pressure of the contents (e.g., vessels in refrigeration or hydrocarbon processing plants with operating systems that do not permit immediate repressurization). For such services, the primary thickness calculations (shell and head) are normally made for the maximum design pressure coincident with the design temperature (MDMT). The ratio of required thickness to nominal thickness as defined in Figure UCS-66.2, Step 3, for the design condition is then calculated. Thickness calculations are also made for other expected pressures at coincident temperature, along with the ΔT difference from the MDMT at design pressure, and the thickness ratio defined in Step 3 of Figure UCS-66.2. The ratio/ΔT points are then plotted on Figure UCS-66.1 (Figure UCS-66.1M). Ratio/ΔT points that are on or below the Figure UCS-66.1 (Figure UCS-66.1M) curve are acceptable, but in no case may the operating temperature be colder than −155°F (−104°C). See also ASME PTB-4–2012, example 3.3. Comparison of pressure–temperature or stress–temperature coincident ratios may also be used as noted in Figure UCS-66.1 (Figure UCS-66.1M).

PART UNF
REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF NONFERROUS MATERIALS

GENERAL

(25) UNF-1 SCOPE

The rules in Part UNF are applicable to pressure vessels and vessel parts that are constructed of nonferrous materials and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements for *Fabrication* in Subsections B and D.

UNF-3 USES

Some of the uses of nonferrous materials are to resist corrosion, to facilitate cleaning of vessels for processing foods, to provide strength or scaling-resistance at high temperatures, and to provide toughness at low temperatures.

UNF-4 CONDITIONS OF SERVICE

Specific chemical compositions, heat-treatment procedures, fabrication requirements, and supplementary tests may be required to assure that the vessel will be in its most favorable condition for the intended service. This is particularly true for vessels subject to severe corrosion. These rules do not indicate the selection of nonferrous material suitable for the intended service or the amount of the corrosion allowance to be provided. It is recommended that users assure themselves by appropriate tests, or otherwise, that the nonferrous material selected will be suitable for the intended service both with respect to corrosion and to retention of satisfactory mechanical properties during the desired service life, taking into account any heating or heat treatment that might be performed during fabrication. See also Section II, Part D, Nonmandatory Appendix A, A-400.

MATERIALS

UNF-5 GENERAL

(a) All nonferrous materials subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Tables UNF-23.1 through UNF-23.5 except as otherwise provided in UG-10 and UG-11.

(b) Nonmandatory Appendix UNF-A and the paragraph entitled *Basis of Purchase* and the appendix of the applicable material specification contain information relative to the fabricating characteristics of the material. They are intended to help the manufacturer in ordering the correct material, and in fabricating it, and to help the producer to select the material best able to fulfill the requirements of the fabricating procedures to be used.

UNF-6 NONFERROUS PLATE

Approved specifications for nonferrous plates are given in Tables UNF-23.1 through UNF-23.5. A tabulation of allowable stress values at different temperatures is given in Section II, Part D, Subpart 1, Table 1B (see UG-5).

UNF-7 FORGINGS

Approved specifications for nonferrous forgings are given in Tables UNF-23.1 through UNF-23.5. A tabulation of allowable stress values at different temperatures is given in Section II, Part D, Subpart 1, Table 1B (see UG-6).

UNF-8 CASTINGS

Approved specifications for nonferrous castings are given in Tables UNF-23.1 through UNF-23.5. A tabulation of allowable stress values at different temperatures is given in Section II, Part D, Subpart 1, Table 1B. These stress values are to be multiplied by the casting quality factors of UG-24. Castings that are to be welded shall be of a weldable grade.

UNF-12 BOLT MATERIALS

(a) Approved specifications for bolt materials are given in Tables UNF-23.1 through UNF-23.5. A tabulation of allowable stress values at different temperatures is given in Section II, Part D, Subpart 1, Table 3.

(b) When bolts are machined from heat treated, hot rolled, or cold worked material and are not subsequently hot worked or annealed, the allowable stress values in Section II, Part D, Subpart 1, Table 3 to be used in design shall be based on the condition of the material selected.

(c) When bolts are fabricated by hot-heading, the allowable stress values for annealed material in Section II, Part D, Subpart 1, Table 3 shall apply unless the manufacturer can furnish adequate control data to show that the tensile properties of hot rolled bars or hot finished forgings are being met, in which case the allowable stress values for the material in the hot finished condition may be used.

(d) When bolts are fabricated by cold heading, the allowable stress values for annealed material in Section II, Part D, Subpart 1, Table 3 shall apply unless the manufacturer can furnish adequate control data to show that higher design stresses, as agreed upon, may be used. In no case shall such stresses exceed the allowable stress values given in Section II, Part D, Subpart 1, Table 3 for cold worked bar stock.

(e) Ferrous bolts, studs, and nuts may be used provided they are suitable for the application. They shall conform to the requirements of UCS-10 and UCS-11.

UNF-13 NUTS AND WASHERS

Nuts and washers may be made from any suitable material listed in Tables UNF-23.1 through UNF-23.5. Nuts may be of any dimension or shape provided their strength is equal to that of the bolting, giving due consideration to bolt hole clearance, bearing area, thread form and class of fit, thread shear, and radial thrust from threads [see U-2(g)].

UNF-14 RODS, BARS, AND SHAPES

Rods, bars and shapes shall conform to one of the specifications in Tables UNF-23.1 through UNF-23.5.

(25) UNF-15 OTHER MATERIALS

(a) Other materials, either ferrous or nonferrous, may be used for parts of vessels provided that they are suitable for the purpose intended.

(b) The user shall ensure that the coupling of dissimilar metals will have no harmful effect on the corrosion rate or service life of the vessel for the service intended.

(c) Other materials used in conjunction with nonferrous metals shall meet the requirements given for those materials in other parts of this Division.

DESIGN

(25) UNF-16 GENERAL

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts of nonferrous materials and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsections B and D.

UNF-19 WELDED JOINTS

(a) For vessels constructed of titanium or zirconium and their alloys, all Category A and B joints shall be of Type No. (1) or No. (2) of Table UW-12.

(b) Titanium or zirconium and their alloys shall not be welded to other materials.

(c) For vessels constructed of UNS N06625, all Category A and B joints shall be Type No. (1) or No. (2) of Table UW-12. All Category C and D joints shall be Type No. (1) or No. (2) of Table UW-12 when the design temperature is 1,000°F (540°C) or higher.

(d) For vessels constructed of UNS N12160, the nominal thickness of the base material at the weld shall not exceed 0.5 in. (13 mm). When welding is performed with filler metal of the same nominal composition as the base metal, only GMAW or GTAW processes are allowed and the nominal weld deposit thickness shall not exceed 0.5 in. (13 mm).

(e) For vessels constructed of UNS N06230 and UNS N06210 and when welding is performed with filler metal of the same nominal composition as the base metal, only GMAW or GTAW processes are allowed. For applications using UNS N06230 above 1,650°F (900°C), welding shall be limited to the GTAW and GMAW welding processes using SFA-5.14, ERNiCrWMo-1.

(f) For vessels constructed of UNS R31233 during weld procedure qualification testing, when using a matching filler metal composition, the minimum specified tensile strength of the weld metal shall be 120 ksi (828 MPa). Longitudinal bend tests are permitted per Section IX, QW-160.

(g) For vessels constructed of UNS N08354, GTAW process with ERNiCrMo filler metals with greater than 12% Mo shall be used when welding this material to itself.

UNF-23 MAXIMUM ALLOWABLE STRESS VALUES

(a) Section II, Part D, Subpart 1, Table 3 for bolting and Table 1B for other materials give the maximum allowable stress values at the temperatures indicated for materials conforming to the specifications listed therein. Values may be interpolated for intermediate temperatures (see UG-23). For vessels designed to operate at a temperature colder than −20°F (−29°C), the allowable stress values to be used in design shall not exceed those given for temperatures of −20°F to 100°F (−29°C to 38°C).

(b) Shells of pressure vessels may be made from welded pipe or tubing listed in Tables UNF-23.1, UNF-23.2, UNF-23.3, UNF-23.4, and UNF-23.5.

(c) When welding or brazing is to be done on material having increased tensile strength produced by hot or cold working, the allowable stress value for the material in the annealed condition shall be used for joint design. One-piece heads and seamless shells may be designed on the basis of the actual temper of the material.

(d) When welding or brazing is to be done on material having increased tensile strength produced by heat treatment, the allowable stress value for the material in the annealed condition shall be used for the joint design unless the stress values for welded construction are given in Section II, Part D, Subpart 1, Table 1B or Table 3 or unless the finished construction is subjected to the same heat

Table UNF-23.1
Nonferrous Metals — Aluminum and Aluminum Alloy Products

Spec. No.	Alloy Designation/UNS No.	Spec. No.	Alloy Designation/UNS No.
SB-26	A02040, A03560, A24430	SB-221	A91060, A91100, A92024, A93003, A95083, A95086, A95154, A95454, A95456, A96061, A96063
SB-108	A02040, A03560	SB-234	Alclad 3003; A91060, A93003, A95052, A95454, A96061
SB-209	Alclad 3003, 3004, 6061; A91060, A91100, A93003, A93004, A95052, A95083, A95086, A95154, A95254, A95454, A95456, A95652, A96061	SB-241	Alclad 3003; A91060, A91100, A93003, A95052, A95083, A95086, A95454, A95456, A96061, A96063
SB-210	Alclad 3003; A91060, A93003, A95052, A95154, A96061, A96063	SB-247	A92014, A93003, A95083, A96061
		SB-308	A96061
SB-211	A92014, A92024, A96061	SB-928	A95083, A95086, A95456

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

treatment as that which produced the temper in the "as-received" material, provided the welded joint and the base metal are similarly affected by the heat treatment.

UNF-28 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figures in Section II, Part D, Subpart 3 and the temperature limits of UG-20(c).

UNF-30 STIFFENING RINGS

Rules covering the design and attachment of stiffening rings are given in UG-29 and UG-30.

UNF-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

Ellipsoidal, torispherical, hemispherical, and conical heads having pressure on the convex side (minus heads) shall be designed by the rules of UG-33, using the applicable figures in Section II, Part D, Subpart 3.

UNF-56 POSTWELD HEAT TREATMENT (25)

(a) Postweld heat treatment of nonferrous materials is not normally necessary nor desirable.

(b) Except as in (c) and (d) below, no postweld heat treatment shall be performed except by agreement between the user and the Manufacturer. The temperature, time and method of heat treatment shall be covered by agreement.

Table UNF-23.2
Nonferrous Metals — Copper and Copper Alloys

Spec. No.	UNS No.	Spec. No.	UNS No.
SB-42	C10200, C12000, C12200	SB-187	C10200, C11000
SB-43	C23000	SB-271	C95200
SB-61	C92200	SB-283	C37700, C64200, C70620, C71520
SB-62	C83600	SB-315	C65500
SB-75	C10200, C12000, C12200, C14200	SB-359	C12200, C44300, C44400, C44500, C70600, C70620, C71000, C71500, C71520
SB-96	C65500		
SB-98	C65100, C65500, C66100	SB-395	C10200, C12000, C12200, C14200, C19200, C23000, C44300, C44400, C44500, C60800, C68700, C70600, C70620, C71000, C71500, C71520
SB-111	C10200, C12000, C12200, C14200, C19200, C23000, C28000, C44300, C44400, C44500, C60800, C68700, C70400, C70600, C70620, C71000, C71500, C71520, C72200	SB-466	C70600, C70620, C71000, C71500, C71520
SB-135	C23000	SB-467	C70600, C70620
SB-148	C95200, C95400, C95820	SB-543	C12200, C19400, C23000, C44300, C44400, C44500, C68700, C70400, C70600, C70620, C71500, C71520
SB-150	C61400, C62300, C63000, C64200		
SB-152	C10200, C10400, C10500, C10700, C11000, C12200, C12300	SB-584	C92200, C93700, C97600
SB-169	C61400	SB-956	C70600, C70620, C71500, C71520
SB-171	C36500, C44300, C44400, C44500, C46400, C46500, C61400, C63000, C70600, C70620, C71500, C71520		

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

Table UNF-23.3 Nonferrous Metals — Nickel, Cobalt, and High Nickel Alloys (25)

Spec. No.	UNS No.
SA-182	N08367
SA-213	N08367
SA-240	N08367
SA-249	N08904
SA-312	N08367
SA-351	J94651
SA-403	N08367
SA-479	N08367
SA-494	N26022, N30002, N30012
SA-688	N08367
SA-965	N08367
SB-127	N04400
SB-160	N02200, N02201
SB-161	N02200, N02201
SB-162	N02200, N02201
SB-163	N02200, N02201, N04400, N06025, N06600, N06601, N08120, N08801, N08800, N08810, N08811, N08825
SB-164	N04400, N04405
SB-165	N04400
SB-166	N06025, N06045, N06600, N06601, N06617, N06690
SB-167	N06025, N06045, N06600, N06601, N06617, N06690
SB-168	N06025, N06045, N06600, N06601, N06617, N06690
SB-333	N10001, N10629, N10665, N10675
SB-335	N10001, N10629, N10665, N10675
SB-366	N02200, N02201, N04400, N06002, N06007, N06022, N06030, N06035, N06045, N06059, N06200, N06210, N06230, N06455, N06600, N06625, N06985, N08020, N08031, N08120, N08330, N08367, N08800, N08825, N10001, N10003, N10242, N10276, N10362, N10629, N10665, N10675, N12160, R20033
SB-407	N08120, N08801, N08800, N08810, N08811
SB-408	N08120, N08800, N08810, N08811
SB-409	N08120, N08800, N08810, N08811
SB-423	N08825
SB-424	N08825
SB-425	N08825
SB-434	N10003, N10242
SB-435	N06002, N06230, N12160, R30556
SB-443	N06625
SB-444	N06625
SB-446	N06625
SB-462	N06022, N06030, N06035, N06045, N06059, N06200, N06686, N08020, N08031, N08367, N10276, N10362, N10629, N10665, N10675, R20033
SB-463	N08020
SB-464	N08020
SB-468	N08020
SB-473	N08020
SB-511	N08330
SB-514	N08120, N08800, N08810
SB-515	N08120, N08800, N08810, N08811
SB-516	N06025, N06045, N06600
SB-517	N06025, N06045, N06600
SB-525	N08330
SB-535	N08330
SB-536	N08330
SB-564	N04400, N06022, N06025, N06035, N06045, N06059, N06200, N06210, N06230, N06600, N06617, N06625, N06686, N08031, N08120, N08367, N08800, N08810, N08811, N08825, N10242, N10276, N10362, N10629, N10665, N10675, N12160, R20033
SB-572	N06002, N06230, N12160, R30556
SB-573	N10003, N10242
SB-574	N06022, N06030, N06035, N06059, N06200, N06210, N06455, N06686, N10276, N10362
SB-575	N06022, N06059, N06035, N06200, N06210, N06455, N06686, N10276, N10362
SB-581	N06007, N06030, N06975, N06985, N08031
SB-582	N06007, N06030, N06975, N06985
SB-599	N08700
SB-619	N06002, N06007, N06022, N06030, N06035, N06059, N06200, N06230, N06455, N06686, N06975, N06985, N06210, N08031, N08320, N10001, N10242, N10276, N10362, N10629, N10665, N10675, N12160, R20033, R30556
SB-620	N08320
SB-621	N08320
SB-622	N06002, N06007, N06022, N06030, N06035, N06059, N06200, N06210, N06230 N06455, N06617, N06686, N06975, N06985, N08031, N08320, N10001, N10242, N10276, N10362, N10629, N10665, N10675, N12160, R20033, R30556
SB-625	N08031, N08354, N08925, R20033
SB-626	N06002, N06007, N06022, N06030, N06035, N06059, N06200, N06210, N06230, N06455, N06617, N06686, N06975, N06985, N08031, N08320, N10001, N10242, N10276, N10362, N10629, N10665, N10675, N12160, R20033, R30556
SB-637	N07718, N07750
SB-649	N08354, N08925, R20033
SB-668	N08028
SB-672	N08700
SB-673	N08354, N08925
SB-674	N08354, N08925
SB-675	N08367
SB-676	N08367
SB-677	N08354, N08904, N08925
SB-688	N08367
SB-690	N08367
SB-691	N08367
SB-704	N06625, N08825
SB-705	N06625, N08825
SB-709	N08028
SB-710	N08330
SB-729	N08020
SB-804	N08367
SB-815	R31233
SB-818	R31233
SF-468	N05500
SF-467	N05500
SF-467M	N05500

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

Table UNF-23.4
Nonferrous Metals — Titanium and Titanium Alloys

Spec. No.	UNS No.	Spec. No.	UNS No.
SB-265	R50250, R50400, R50550, R52250, R52252, R52254, R52400, R52402, R52404, R53400, R54250, R56320, R56323	SB-367	R50400, R50550, R52400, R54250
SB-338	R50250, R50400, R50550, R52400, R52402, R52404, R53400, R54250, R56320, R56323	SB-381	R50250, R50400, R50550, R52400, R52402, R52404, R53400, R54250, R56323
SB-348	R50250, R50400, R50550, R52400, R52402, R52404, R53400, R54250, R56323	SB-861	R50250, R50400, R50550, R52400, R52402, R52404, R53400, R54250, R56320, R56323
SB-363	R50250, R50400, R50550, R52400, R52404, R53400, R54250, R56323	SB-862	R50250, R50400, R50550, R52400, R52402, R52404, R53400, R54250, R56320, R56323

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

(c) Within 14 days after welding, all products of zirconium Grade R60705 shall be heat treated at 1,000°F to 1,100°F (540°C to 595°C) for a minimum of 1 hr for thicknesses up to 1 in. (25 mm) plus $^1/_2$ hr for each additional inch of thickness. Above 800°F (425°C), cooling shall be done in a closed furnace or cooling chamber at a rate not greater than 500°F/hr (278°C/h) divided by the maximum metal thickness of the shell or head material in inches but in no case more than 500°F/hr (278°C/h). From 800°F (425°C), the vessel may be cooled in still air. For tube-to-tubesheet welds, when postweld heat treatment is performed with no other components, the cooling rate above 800°F (425°C) shall not exceed 250°F/hr (140°C/h) regardless of thickness.

(d) Postweld Heat Treatment of UNS Nos. N08800, N08810, and N08811 Alloys

(1) Pressure boundary welds and welds to pressure boundaries in vessels with design temperatures above 1,000°F (540°C)fabricated from UNS No. N08800 (Alloy 800), UNS No. N08810 (Alloy 800H), and UNS No. N08811 (Alloy 800HT) shall be postweld heat treated. The postweld heat treatment shall consist of heating to a minimum temperature of 1,625°F (885°C) for $1^1/_2$ hr for thicknesses up to 1 in. (25 mm), and for $1^1/_2$ hr + 1 hr/in. of thickness for thicknesses in excess of 1 in. (25 mm). Cooling and heating rates shall be by agreement between the user or the user's designated agent and the Manufacturer. As an alternative, solution annealing in accordance with the material specification is acceptable. Postweld heat treatment of tube-to-tubesheet and expansion bellows attachment welds is neither required nor prohibited.

(2) Except as permitted in (3) below, vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after welded repairs have been made.

(3) Weld repairs to the weld metal and heat-affected zone in welds joining these materials may be made after the final PWHT, but prior to the final hydrostatic test, without additional PWHT. The weld repairs shall meet the requirements of (-a) through (-d) below.

(-a) The Manufacturer shall give prior notification of the repair to the user or to the user's designated agent and shall not proceed until acceptance has been obtained.

(-b) The total repair depth shall not exceed $^1/_2$ in. (13 mm) or 30% of the material thickness, whichever is less. The total depth of a weld repair shall be taken as the sum of the depths for repairs made from both sides of a weld at a given location.

(-c) After removal of the defect, the groove shall be examined. The weld repair area must also be examined. The liquid penetrant examination method, in accordance with Mandatory Appendix 8, shall be used.

Table UNF-23.5
Nonferrous Metals — Zirconium

Spec. No.	UNS No.	Spec. No.	UNS No.
SB-493	R60702, R60705	SB-653	R60702, R60705
SB-523	R60702	SB-658	R60702, R60705
SB-550	R60702, R60705	SB-752	R61702, R61705
SB-551	R60702, R60705		

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

(-d) The vessel shall be hydrostatically tested after making the welded repair.

(e) Postweld heat treatment of UNS R31233 is required prior to cold forming when the cold forming bend radius at the weld is less than 4 times the thickness of the component. Postweld treatment shall consist of annealing at 2,050°F (1 121°C) immediately followed by water quenching.

UNF-57 RADIOGRAPHIC EXAMINATION

(a) Vessels or parts of vessels constructed of nonferrous materials shall be radiographed in accordance with the requirements of UW-11.

(b) In addition, for vessels constructed of titanium or zirconium and their alloys, all Category A and B joints shall be fully radiographed in accordance with UW-51.

(c) Welded butt joints in vessels constructed of materials listed in Table UNF-23.3, with the exception of alloys 200 (UNS No. N02200), 201 (UNS No. N02201), 400 (UNS No. N04400), 401 (UNS No. N04401), and 600 (UNS No. N06600), shall be examined radiographically for their full length as prescribed in UW-51 when the thinner of the plate or vessel wall thicknesses at the welded joint exceeds $^3/_8$ in. (10 mm).

(d) Where a defect is removed and welding repair is not necessary, care shall be taken to contour notches or corners. The contoured surface shall then be reinspected by the same means originally used for locating the defect to be sure it has been completely removed.

UNF-58 LIQUID PENETRANT EXAMINATION

(a) All welds, both groove and fillet, in vessels constructed of materials covered by UNS N06625 (for Grade 2 only in SB-443, SB-444, and SB-446), UNS N10001, and UNS N10665 shall be examined for the detection of cracks by the liquid penetrant method. This examination shall be made following heat treatment if heat treatment is performed. All cracks shall be removed by grinding, or grinding and filing. Where a defect is removed and welding repair is not necessary, care shall be taken to contour notches or corners. The contoured surface shall then be reinspected by the same means originally used for locating the defect to be sure it has been completely removed.

(b) All joints in vessels constructed of titanium or zirconium and their alloys shall be examined by the liquid penetrant method of Mandatory Appendix 8.

(c) Welded joints in vessels or parts of vessels, constructed of materials listed in Table UNF-23.3, with the exception of alloys 200 (UNS No. N02200), 201 (UNS No. N02201), 400 (UNS No. N04400), 405 (UNS No. N04405), and 600 (UNS No. N06600), shall be examined by the liquid penetrant method when they are not required to be fully radiographed.

(d) Laser and resistance-welded lap joints are exempt from liquid penetrant examination requirements of (a), (b), and (c) above.

UNF-65 LOW TEMPERATURE OPERATION (25)

(a) The materials listed in Tables UNF-23.1 through UNF-23.5, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, no additional requirements are specified for

(1) wrought aluminum alloys when they are used at temperatures down to −452°F (−269°C)

(2) copper and copper alloys and cast aluminum alloys when they are used at temperatures down to −325°F (−198°C)

(3) titanium or zirconium and their alloys used at temperatures down to −75°F (−59°C)

(4) nickel and nickel alloys when they are used at temperatures down to −325°F (−198°C), except as described in (b)

The materials listed in Tables UNF-23.1 through UNF-23.5 may be used at lower temperatures than those specified herein and for other weld metal compositions, provided the user ensures by suitable test results such as determinations of tensile elongation and sharp-notch tensile strength (compared to unnotched tensile strength) that the material has suitable ductility at the design temperature.

(b) Precipitation-hardening nickel alloys UNS N07718 and UNS N07750 shall be impact tested in accordance with UHT-6 at no warmer than MDMT. The test results shall meet UHT-6 requirements.

FABRICATION

UNF-75 GENERAL (25)

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of nonferrous materials and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsections B and D.

UNF-77 FORMING SHELL SECTIONS AND HEADS

The following provisions shall apply in addition to the general rules for forming given in UG-79:

(a) The selected thickness of material shall be such that the forming processes will not reduce the thickness of the material at any point below the minimum value required by the design computation.

(b) Relatively small local bulges and buckles may be removed from formed parts for shells and heads by hammering or by local heating and hammering. For limiting temperatures see Nonmandatory Appendix UNF-A.

(c) A shell section that has been formed by rolling may be brought true-to-round for its entire length by pressing, rolling, or hammering.

(25) ## UNF-78 WELDING

Welding of titanium or zirconium and their alloys is to be by the gas-shielded tungsten arc process, the gas-shielded metal arc (consumable-electrode) process, the plasma arc welding process, the electron beam process, the laser beam process, or the resistance welding process, meeting the requirements of Section IX or Part UDA, whichever is applicable.

UNF-79 REQUIREMENTS FOR POSTFABRICATION HEAT TREATMENT DUE TO STRAINING

(a) The following rules shall apply in addition to general rules for forming given in UNF-77.

(1) If the following conditions prevail, the cold formed areas of pressure-retaining components manufactured of austenitic alloys shall be solution annealed by heating at the temperatures given in Table UNF-79 for 20 min/in. (20 min/25 mm) of thickness followed by rapid cooling:

(-a) the finishing-forming temperature is below the minimum heat-treating temperature given in Table UNF-79; and

(-b) the design metal temperature and the forming strains exceed the limits shown in Table UNF-79.

(2) Forming strains shall be determined by the equations in Table UG-79-1.

(b) When forming strains cannot be calculated as shown in (a) above, the Manufacturer shall have the responsibility to determine the maximum forming strain. For flares, swages, or upsets, heat treatment in accordance with Table UNF-79 shall apply, regardless of the amount of strain.

INSPECTION AND TESTS

UNF-90 GENERAL (25)

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are constructed of nonferrous materials and

Table UNF-79
Postfabrication Strain Limits and Required Heat Treatment

Grade	UNS Number	Limitation in Lower Temperature Range — For Design Temperature, °F (°C) — Exceeding	But Less Than or Equal To	And Forming Strains Exceeding, %	Limitations in Higher Temperature Range — For Design Temperature, °F (°C), Exceeding	And Forming Strain Exceeding, %	Minimum Heat Treatment Temperature, °F (°C), When Design Temperature and Forming Strain Limits Are Exceeded [Note (1)], [Note (2)]
...	N06002	1,000 (540)	1,250 (675)	15	1,250 (675)	10	2,025 (1 105)
...	N06022	1,075 (580)	1,250 (675)	15	...	...	2,050 (1 120)
...	N06025	1,075 (580)	1,200 (650)	20	1,200 (650)	10	2,200 (1 205)
...	N06045	1,100 (595)	1,250 (675)	15	1,250 (675)	10	2,150 (1 175)
...	N06059	1,075 (580)	1,250 (675)	15	1,250 (675)	10	2,050 (1 120)
...	N06230	1,100 (595)	1,400 (760)	15	1,400 (760)	10	2,200 (1 205)
600	N06600	1,075 (580)	1,200 (650)	20	1,200 (650)	10	1,900 (1 040)
601	N06601	1,075 (580)	1,200 (650)	20	1,200 (650)	10	1,900 (1 040)
617	N06617	1,000 (540)	1,250 (675)	15	1,250 (675)	10	2,100 (1 150)
625	N06625	1,000 (540)	1,250 (675)	15	1,250 (675)	10	2,000 (1 095)
690	N06690	1,075 (580)	1,200 (650)	20	1,200 (650)	10	1,900 (1 040)
...	N08120	1,100 (595)	1,250 (675)	15	1,250 (675)	10	2,175 (1 190)
...	N08330	1,100 (595)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
800	N08800	1,100 (595)	1,250 (675)	15	1,250 (675)	10	1,800 (980)
800H	N08810	1,100 (595)	1,250 (675)	15	1,250 (675)	10	2,050 (1 120)
...	N08811	1,100 (595)	1,250 (675)	15	1,250 (675)	10	2,100 (1 150)
...	N10003	1,100 (595)	1,250 (675)	15	1,250 (675)	10	2,150 (1 175)
...	N10276	1,050 (565)	1,250 (675)	15	1,250 (675)	10	2,050 (1 120)
...	N12160	1,050 (565)	1,250 (675)	15	1,250 (675)	10	1,950 (1 065)
...	R30556	1,100 (595)	1,250 (675)	15	1,250 (675)	10	2,150 (1 175)

GENERAL NOTES:
(a) The limits shown are for cylinders formed from plates, spherical or dished heads formed from plate, and tube and pipe bends.
(b) When the forming strains cannot be calculated as shown in UNF-79(a), the forming strain limits shall be half those tabulated in this Table [see UNF-79(b)].

NOTES:
(1) Rate of cooling from heat-treatment temperature is not subject to specific control limits.
(2) The temperature indicated is the minimum furnace set point, and load temperatures as much as 25°F (15°C) below the set temperature are acceptable.

shall be used in conjunction with the general requirements for *Inspection Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsections B and D.

UNF-91 REQUIREMENTS FOR THE IMAGE QUALITY INDICATOR

If the filler metal is radiographically similar[53] to the base metal, the image quality indicator may be placed adjacent to the weld; otherwise it shall be placed on the deposited weld metal.

UNF-95 WELDING TEST PLATES

If a vessel of welded titanium or zirconium and their alloys construction incorporates joints of Category A or B as described in UW-3, a production test plate of the same specification, grade, and thickness shall be made of sufficient size to provide at least one face and one root bend specimen or two side bend specimens dependent upon plate thickness. Where longitudinal joints are involved, the test plate shall be attached to one end of the longitudinal joint and welded continuously with the joint. Where circumferential joints only are involved, the test plate need not be attached but shall be welded along with the joint and each welder or welding operator shall deposit weld metal in the test plate at the location and proportional to that deposited in the production weld. Test plates shall represent each welding process or combination of processes or a change from machine to manual or vice versa. At least one test plate is required for each vessel provided not over 100 ft of Category A or B joints are involved. An additional test plate, meeting the same requirements as outlined above, shall be made for each additional 100 ft of Category A or B joints involved. The bend specimens shall be prepared and tested in accordance with Section IX, QW-160. Failure of either bend specimen constitutes rejection of the weld.

MARKING AND REPORTS

UNF-115 GENERAL

The provisions for marking and reports in UG-115 through UG-120 shall apply without supplement to pressure vessels constructed of nonferrous materials.

NONMANDATORY APPENDIX UNF-A CHARACTERISTICS OF THE NONFERROUS MATERIALS

(Informative)

UNF-A-1 PURPOSE

This Appendix summarizes the major properties and fabricating techniques suitable for the nonferrous materials.

UNF-A-2 GENERAL

The nonferrous materials can be formed and fabricated into a variety of types of assemblies with the same types of fabricating equipment as are used for steel. The details of some fabricating procedures vary among the several nonferrous materials and differ from those used for steel because of differences in the inherent mechanical properties of these materials. Detailed information regarding procedures best suited to the several metals may be obtained from the literature of the material producers, and from other reliable sources such as the latest editions of handbooks issued by the American Welding Society and the American Society for Metals.

UNF-A-3 PROPERTIES

The specified mechanical properties, as listed in Section II, Part D, Subpart 1, Tables 1B and 3, show a wide range of strengths. The maximum allowable stress values show a correspondingly wide range and a variable relationship to service temperature. The maximum temperature listed for any material is the temperature above which that material is not customarily used. Section II, Part D, Subpart 2, Table PRD provides Poisson's ratios and densities for ferrous and nonferrous materials.

UNF-A-4 MAGNETIC PROPERTIES

See Section II, Part D, Nonmandatory Appendix A, A-410.

UNF-A-5 ELEVATED TEMPERATURE EFFECTS

See Section II, Part D, Nonmandatory Appendix A, A-420.

UNF-A-6 LOW TEMPERATURE BEHAVIOR

See Section II, Part D, Nonmandatory Appendix A, A-430.

UNF-A-7 THERMAL CUTTING

In general, nonferrous materials cannot be cut by the conventional oxyacetylene cutting equipment commonly used for steel. They may be melted and cut by oxyacetylene, powder cutting carbon arc, oxygen arc, and other means. When such thermal means for cutting are employed a shallow contaminated area adjacent to the cut results. This contamination should be removed by grinding, machining, or other mechanical means after thermal cutting and prior to use or further fabrication by welding.

UNF-A-8 MACHINING

The nonferrous materials can be machined with properly sharpened tools of high-speed steel or cemented-carbide tools. A coolant is necessary and should be used copiously. In general, the tools should have more side and top rake than required for cutting steel and the edges should be keen and smooth. Comparatively high speeds and fine feeds give best results. Information can be obtained from the material producers and the Metals Handbook for conditions to give optimum results.

UNF-A-9 GAS WELDING

The commonly used gas processes for welding aluminum-base materials employ oxyhydrogen or oxyacetylene flames whereas only the latter produces sufficient heat for welding the copper-base and nickel-base alloys. For the aluminum, nickel and cupro-nickel alloys a neutral to slightly reducing flame should be used, whereas for copper base materials the flame should be neutral to slightly oxidizing. A suitable flux, applied to the welding rod and the work, shall be used except that no flux is required for nickel. Boron-free and phosphorusfree fluxes are required for nickel–copper alloy and for nickel–chromium–iron alloy. Residual deposits of flux shall be removed.

UNF-A-10 METAL ARC WELDING

Metal arc welds can be made with standard dc equipment using reversed polarity (electrode-positive) and coated electrodes. A slightly greater included angle in butt welds for adequate manipulation of the electrode is required.

UNF-A-11 INERT GAS METAL ARC WELDING

Both the consumable and nonconsumable electrode processes are particularly advantageous for use with the nonferrous materials. Best results are obtained through the use of special filler metals.

UNF-A-12 RESISTANCE WELDING

Electric resistance welding, which includes spot, line or seam, and butt or flash welding, can be used with the nonferrous materials. Proper equipment and technique are required for making satisfactory welds.

UNF-A-13 CORROSION

See Section II, Part D, Nonmandatory Appendix A, A-440.

UNF-A-14 SPECIAL COMMENTS

(a) Aluminum. See Section II, Part D, Nonmandatory Appendix A, A-451.

(b) Nickel. See Section II, Part D, Nonmandatory Appendix A, A-452.

(c) Titanium or Zirconium. See Section II, Part D, Nonmandatory Appendix A, A-453.

PART UHA
REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF HIGH ALLOY STEEL

GENERAL

(25) UHA-1 SCOPE

The rules in Part UHA are applicable to pressure vessels and vessel parts that are constructed of high alloy steel and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements for *Fabrication* in Subsections B and D.

UHA-5 USES

Some of the uses of high alloy steel are to resist corrosion, to avoid contamination of contents with iron, to facilitate cleaning of vessels for processing foods, to provide strength or scaling resistance at high temperatures, and to provide impact resistance at low temperatures.

UHA-6 CONDITIONS OF SERVICE

Specific chemical compositions, heat treatment procedures, fabrication requirements, and supplementary tests may be required to assure that the vessel will be in its most favorable condition for the intended service. This is particularly true for vessels subject to severe corrosion. These rules do not indicate the selection of an alloy suitable for the intended service or the amount of the corrosion allowance to be provided.

It is recommended that users assure themselves by appropriate tests, or otherwise, that the high alloy steel selected and its heat treatment during fabrication will be suitable for the intended service both with respect to corrosion resistance and to retention of satisfactory mechanical properties during the desired service life. (See Nonmandatory Appendix UHA-A, Suggestions on the Selection and Treatment of Austenitic Chromium–Nickel Steels.)

UHA-8 MATERIAL

(a) Approved specifications for castings of high alloy steel are given in Table UHA-23. A tabulation of allowable stress values at different temperatures is given in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other materials. These stress values are to be multiplied by the casting quality factors of UG-24. Castings that are to be welded shall be of weldable grade.

(b) Cast high alloy steel flanges and fittings complying with ASME B16.5 shall be used within the ratings assigned in these standards.

MATERIALS

UHA-11 GENERAL

(a) All materials subject to stress due to pressure shall conform to one of the specifications given in Section II, and shall be limited to those listed in Table UHA-23 except as otherwise provided in (b) and UG-4.

(b) The specifications listed in Section II, Part D, Subpart 1, Tables 1A and 3 do not use a uniform system for designating the Grade number of materials that have approximately the same range of chemical composition. To provide a uniform system of reference, these tables include a column of UNS (Unified Numbering System) numbers assigned to identify the various alloy compositions. When these particular UNS numbers were assigned, the familiar AISI type numbers for stainless steels were incorporated into the designation. These type numbers are used in the rules of Part UHA whenever reference is made to materials of approximately the same chemical composition that are furnished under more than one approved specification or in more than one product form.

UHA-12 BOLT MATERIALS

(a) Approved specifications for bolt materials of carbon steel and low alloy steel are listed in Table UCS-23 and of high alloy steel in Table UHA-23. A tabulation of allowable stress values at different temperatures (see UG-12) is given in Section II, Part D, Subpart 1, Table 3.

(b) Nonferrous bolts, studs, and nuts may be used provided they are suitable for the application. They shall conform to the requirements of Part UNF.

UHA-13 NUTS AND WASHERS

Nuts and washers shall conform to the requirements in UCS-11.

DESIGN

(25) UHA-20 GENERAL

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are constructed of high alloy steel and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsections B and D.

UHA-21 WELDED JOINTS

When radiographic examination is required for butt-welded joints by UHA-33, Category A and B joints (see UW-3) shall be of Type Nos. (1) and (2) of Table UW-12.

UHA-23 MAXIMUM ALLOWABLE STRESS VALUES

(a) Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other materials give the maximum allowable stress values at the temperatures indicated for the materials conforming to the specifications listed therein. Values may be interpolated for intermediate temperatures (see UG-23).

(b) Shells of pressure vessels may be made from welded pipe or tubing listed in Table UHA-23.

(c) For vessels designed to operate at a temperature below −20°F (−30°C), the allowable stress values to be used in design shall not exceed those given in Section II, Part D, Subpart 1, Table 1A or Table 3 for temperatures of −20°F to 100°F (−30°C to 40°C).

UHA-28 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figures in Section II, Part D, Subpart 3 and the temperature limits of UG-20(c).

UHA-29 STIFFENING RINGS FOR SHELLS UNDER EXTERNAL PRESSURE

Rules covering the design of stiffening rings are given in UG-29.

UHA-30 ATTACHMENT OF STIFFENING RINGS TO SHELL

Rules covering the attachment of stiffening rings are given in UG-30.

UHA-31 FORMED HEADS, PRESSURE ON CONVEX SIDE

Ellipsoidal, torispherical, hemispherical, and conical heads, having pressure on the convex side (minus heads), shall be designed by the rules of UG-33, using the applicable figures in Section II, Part D, Subpart 3.

UHA-32 REQUIREMENTS FOR POSTWELD HEAT TREATMENT (25)

(a) Before applying the detailed requirements and exemptions in these paragraphs, satisfactory weld procedure qualifications of the procedures to be used shall be performed in accordance with all the essential variables of Section IX including conditions of postweld heat treatment or lack of postweld heat treatment and including other restrictions listed below. Welds in pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than specified in Tables UHA-32-1 through UHA-32-7 when the nominal thickness, as defined in UW-40.6, including corrosion allowance, exceeds the limits in the Notes to Tables UHA-32-1 through UHA-32-7. The exemptions provided for in the Notes to Tables UHA-32-1 through UHA-32-7 are not permitted when welding ferritic materials greater than $^1/_8$ in. (3 mm) thick with the electron beam welding process, or when welding P-Nos. 6 and 7 (except for Type 405 and Type 410S) materials of any thickness using the inertia and continuous drive friction welding processes. The materials in Tables UHA-32-1 through UHA-32-7 are listed in accordance with the Section IX P-Number material groupings of Section IX, Table QW/QB-422 and are also listed in Table UHA-23.

(b) Holding temperatures and/or holding times in excess of the minimum values given in Tables UHA-32-1 through UHA-32-7 may be used. The holding time at temperature as specified in Tables UHA-32-1 through UHA-32-7 need not be continuous. It may be an accumulation of time of multiple postweld heat treat cycles. Long time exposure to postweld heat treatment temperatures may cause sigma phase formation (see Nonmandatory Appendix UHA-A).

(c) When pressure parts of two different P-Number groups are joined by welding, engineering judgment shall be applied when selecting the postweld heat treatment temperature and holding time to produce material properties suitable for the intended service. Alternatives such as welding with buttering as described in Section IX, QW-283 may be considered. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control. Ferritic steel parts, when used in conjunction with austenitic chromium–nickel stainless steel parts or austenitic/ferritic duplex steel, shall not be subjected to the solution heat treatment described in Nonmandatory Appendix UHA-A.

(d) The operation of postweld heat treatment shall be carried out by one of the procedures given in UW-40 in accordance with the requirements of UCS-56.4 through UCS-56.6 except as modified by the Notes to Tables UHA-32-1 through UHA-32-7.

(e) Vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after repairs have been made.

(25)

Table UHA-23
High Alloy Steel

Spec. No.	UNS No.	Type/Grade
SA-182	N08904	F904L
	S20910	FXM-19
	S21904	FXM-11
	S30400	F304
	S30403	F304L
	S30409	F304H
	S30453	F304LN
	S30815	F45
	S31000	F310
	S31050	F310MoLN
	S31254	F44
	S31266	F58
	S31600	F316
	S31603	F316L
	S31609	F316H
	S31700	F317
	S31703	F317L
	S31803	F51
	S32053	F73
	S32100	F321
	S32109	F321H
	S32202	F66
	S32205	F60
	S32506	...
	S32750	...
	S32750	F53
	S32760	F55
	S34700	F347
	S34709	F347H
	S34800	F348
	S34809	F348H
	S39274	F54
	S41000	F6a Cl. 1 & 2
	S44627	FXM-27Cb
SA-193	S21800	B8S, B8SA
	S30400	B8 Cl. 1 & 2
	S30451	B8NA Cl. 1A
	S30500	B8P Cl. 1 & 2
	S31600	B8M Cl. 1 & 2, B8M2 Cl. 2B
	S31651	B8MNA Cl. 1A
	S32100	B8T Cl. 1 & 2
	S34700	B8C Cl. 1 & 2
	S41000	B6
SA-213	S20910	XM-19
	S30400	TP304
	S30403	TP304L
	S30409	TP304H
	S30432	...
	S30451	TP304N
	S30453	TP304LN
	S30815	...
	S30908	TP309S
	S30909	TP309H
	S30940	TP309Cb
	S31002	...
	S31008	TP310S
	S31009	TP310H
	S31040	TP310Cb
	S31050	TP310MoLN
	S31254	...
	S31277	...
	S31600	TP316
	S31603	TP316L
	S31609	TP316H
	S31651	TP316N
	S31725	...
SA-213	S32100	TP321
	S32109	TP321H
	S34700	TP347
	S34709	TP347H
	S34751	TP347LN
	S34800	TP348
	S34809	TP348H
	S38100	XM-15
	S38815	...
SA-217	J91150	CA15
SA-240	N08904	904L
	S20100	201-1, 201-2
	S20153	201LN
	S20400	204
	S20910	XM-19
	S24000	XM-29
	S30100	301
	S30200	302
	S30400	304
	S30403	304L
	S30409	304H
	S30451	304N
	S30453	304LN
	S30815	...
	S30908	309S
	S30909	309H
	S30940	309Cb
	S31008	310S
	S31009	310H
	S31040	310Cb
	S31050	310MoLN
	S31200	...
	S31254	...
	S31260	...
	S31266	...
	S31277	...
	S31600	316
	S31603	316L
	S31609	316H
	S31635	316Ti
	S31640	316Cb
	S31651	316N
	S31655	...
	S31700	317
	S31703	317L
	S31725	...
	S31803	...
	S32003	...
	S32053	...
	S32100	321
	S32101	...
	S32109	321H
	S32202	...
	S32205	2205
	S32304	...
	S32506	...
	S32550	...
	S32750	...
	S32760	...
	S32900	329
	S32906	...
	S32950	...
	S34700	347
	S34709	347H
	S34800	348
	S38100	XM-15
	S38815	...
SA-240	S40500	405
	S40910	...
	S40920	...
	S40930	...
	S41000	410
	S41008	410S
	S42900	429
	S43000	430
	S43932	...
	S44400	...
	S44626	XM-33
	S44627	XM-27
	S44635	...
	S44660	26-3-3
	S44700	...
	S44800	...
SA-249	N08904	...
	S20910	TPXM-19
	S24000	TPXM-29
	S30400	TP304
	S30403	TP304L
	S30409	TP304H
	S30451	TP304N
	S30453	TP304LN
	S30815	...
	S30908	TP309S
	S30909	TP309H
	S30940	TP309Cb
	S31008	TP310S
	S31009	TP310H
	S31040	TP310Cb
	S31050	TP310MoLN
	S31254	...
	S31266	...
	S31277	...
	S31600	TP316
	S31603	TP316L
	S31609	TP316H
	S31651	TP316N
	S31700	TP317
	S31703	TP317L
	S31725	...
	S32053	...
	S32100	TP321
	S32109	TP321H
	S34700	TP347
	S34709	TP347H
	S34800	TP348
	S34809	TP348H
	S38100	TPXM-15
	S38815	...
SA-268	S40500	TP405
	S40800	...
	S40900	TP409
	S41000	TP410
	S42900	TP429
	S43000	TP430
	S43035	TP439
	S43036	TP430Ti
	S44400	...
	S44600	TP446-1, TP446-2
	S44626	XM-33
	S44627	XM-27
	S44635	...
	S44660	26-3-3
	S44700	29-4
	S44735	...

Table UHA-23
High Alloy Steel (Cont'd)

Spec. No.	UNS No.	Type/Grade
SA-268	S44800	29-4-2
SA-312	N08904	...
	S20910	TPXM-19
	S21904	TPXM-11
	S24000	TPXM-29
	S30400	TP304
	S30403	TP304L
	S30409	TP304H
	S30451	TP304N
	S30453	TP304LN
	S30815	...
	S30908	TP309S
	S30909	TP309H
	S30940	TP309Cb
	S31002	...
	S31008	TP310S
	S31009	TP310H
	S31040	TP310Cb
	S31050	TP310MoLN
	S31254	...
	S31600	TP316
	S31603	TP316L
	S31609	TP316H
	S31651	TP316N
	S31700	TP317
	S31703	TP317L
	S31725	...
	S32053	...
	S32100	TP321
	S32109	TP321H
	S34700	TP347
	S34709	TP347H
	S34751	TP347LN
	S34800	TP348
	S34809	TP348H
	S38100	TPXM-15
	S38815	...
SA-320	S30323	B8F Cl. 1, B8FA Cl. 1A
	S30400	B8 Cl. 1 & 2, B8A Cl. 1A
	S31600	B8M Cl. 1 & 2, B8MA Cl. 1A
	S32100	B8T Cl. 1 & 2, B8TA Cl. 1A
	S34700	B8C Cl. 1 & 2, B8CA Cl. 1A
SA-351	J92500	CF3, CF3A
	J92590	CF10
	J92600	CF8, CF8A
	J92710	CF8C
	J92800	CF3M
	J92900	CF8M
	J92901	CF10M
	J93000	CG8M
	J93254	CK3MCuN
	J93400	CH8
	J93402	CH20
	J93790	CG6MMN
	J94202	CK20
	...	CT15C
	J95150	CN7M
SA-358	S31254	...
	S31266	...
	S31725	...
SA-376	S30400	TP304
	S30409	TP304H
	S30451	TP304N
SA-376	S30453	TP304LN
	S31600	TP316
	S31609	TP316H
	S31651	TP316N
	S31725	...
	S32053	...
	S32100	TP321
	S32109	TP321H
	S34700	TP347
	S34709	TP347H
	S34800	TP348
SA-403	N08904	904L
	S20910	XM-19
	S30400	304
	S30403	304L
	S30409	304H
	S30451	304N
	S30453	304LN
	S30900	309
	S31008	310S
	S31600	316
	S31603	316L
	S31609	316H
	S31651	316N
	S31700	317
	S31703	317L
	S31725	...
	S32053	WPS32053, CRS32053
	S32100	321
	S32109	321H
	S34700	347
	S34709	347H
	S34800	348
	S34809	348H
	S38815	...
SA-409	S31725	...
	S32053	...
SA-451	J92800	CPF3M
	J92900	CPF8M
SA-453	S63198	651 Cl. A & B
	S66286	660 Cl. A & B
SA-479	N08904	...
	S20910	XM-19
	S24000	XM-29
	S30200	302
	S30400	304
	S30403	304L
	S30409	304H
	S30453	304LN
	S30815	...
	S30908	309S
	S30909	309H
	S30940	309Cb
	S31008	310S
	S31009	310H
	S31040	310Cb
	S31600	316
	S31603	316L
	S31725	...
	S31803	...
	S32053	...
	S32100	321
	S32101	...
	S32109	321H
	S32202	...
	S32205	...
SA-479	N08904	...
	S32506	...
	S32550	...
	S32760	...
	S32906	...
	S34700	347
	S34800	348
	S38815	...
	S40500	405
	S41000	410
	S43000	430
	S43035	439
	S44627	XM-27
	S44700	...
	S44800	...
SA-564	S17400	630
SA-638	S66286	660
SA-666	S20100	201-1, 201-2
	S21904	XM-11
SA-688	S24000	TPXM-29
	S30400	TP304
	S30403	TP304L
	S30451	TP304N
	S30453	TP304LN
	S31600	TP316
	S31603	TP316L
SA-693	S17400	630
SA-705	S17400	630
SA-747	J92180	CB7Cu-1
SA-789	S31260	...
	S31500	...
	S31803	...
	S32003	...
	S32101	...
	S32202	...
	S32205	...
	S32304	...
	S32506	...
	S32550	...
	S32707	...
	S32750	...
	S32760	...
	S32900	...
	S32906	...
	S32950	...
	S39274	...
SA-790	S31260	...
	S31500	...
	S31803	...
	S32003	...
	S32101	...
	S32202	...
	S32205	...
	S32304	...
	S32506	...
	S32550	...
	S32707	...
	S32750	...
	S32760	...
	S32900	...
	S32906	...
	S32950	...
	S39274	...
SA-803	S30453	TP304LN
	S43035	TP439
	S44660	26-3-3
SA-813	S30453	TP304LN

Table UHA-23
High Alloy Steel (Cont'd)

Spec. No.	UNS No.	Type/Grade	Spec. No.	UNS No.	Type/Grade	Spec. No.	UNS No.	Type/Grade
	S30908	TP309S	SA-965	S30453	F304LN	SA/EN	...	X2CrNi18–9
	S30940	TP309Cb		S31000	F310	10028-7	...	X2CrNiMo17–12–2
	S31008	TP310S		S31600	F316	[Note (1)]	...	X2CrNiMoN17–11–2
	S31040	TP310Cb		S31603	F316L		...	X2CrNiMoN17–13–3
SA-814	S30908	TP309S		S31609	F316H		...	X2CrNiN18–10
	S30940	TP309Cb		S31651	F316N		...	X5CrNi18–10
	S31008	TP310S		S32100	F321		...	X5CrNiMo17–12–2
	S31040	TP310Cb		S32109	F321H		...	X5CrNiN19–9
SA-815	S31803	...		S34700	F347		...	X6CrNiTi18–10
	S32101	...		S34709	F347H	SA/JIS G4303	...	SUS302
	S32202	...		S34800	F348		...	SUS304
	S32205	...		S34809	F348H		...	SUS304L
	S32760	...	SA-995	J92205	4A		...	SUS310S
SA-965	S21904	FXM-11		J93345	2A		...	SUS316
	S30400	F304		J93380	6A		...	SUS316L
	S30403	F304L	SA-1010	S41003	40, 50		...	SUS321
	S30409	F304H					...	SUS347
	S30451	F304N					...	SUS405

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

NOTE:
(1) For the rules of this Part and for Mandatory Appendix 44, SA/EN 10028-7 materials shall be considered as SA-240 materials with the following corresponding grades:
- *(a)* X2CrNi18–9 shall be considered as Type 304L.
- *(b)* X2CrNiMo17–12–2 shall be considered as Type 316L.
- *(c)* X2CrNiMoN17–11–2 and X2CrNiMoN17–13–3 shall be considered as Type 316LN.
- *(d)* X2CrNiN18–10 shall be considered as Type 304LN.
- *(e)* X5CrNi18–10 shall be considered as Type 304.
- *(f)* X5CrNiMo17–12–2 shall be considered as Type 316.
- *(g)* X5CrNiN19–9 shall be considered as Type 304N.
- *(h)* X6CrNiTi18–10shall be considered as Type 321.

(**25**)

Table UHA-32-1
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 6

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UHA-32(d)] Up to 2 in. (50 mm)	Over 2 in. (50 mm)
P-No. 6 Gr. Nos. 1, 2, 3	1,400 (760)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

GENERAL NOTES:
(a) Postweld heat treatment is not required when conditions (1) through (4) below are met.
- *(1)* vessels are constructed of alloy UNS S41000
- *(2)* vessels have a carbon content not exceeding 0.08 %
- *(3)* vessels are welded with electrodes that produce
  - *(a)* an austenitic chromium-nickel weld deposit, or
  - *(b)* a non-air-hardening nickel-chromium-iron weld deposit
- *(4)* vessels have a nominal thickness
  - *(a)* not exceeding $^3/_8$ in. (10 mm) or
  - *(b)* exceeding $^3/_8$ in. (10 mm) but not greater than $1^1/_2$ in. (38 mm) for full-penetration welds in butt joints when
    - *(-1)* a preheat of 450°F (230°C) is maintained during welding and
    - *(-2)* the joints are completely radiographed

(b) Postweld heat treatment shall be performed as prescribed in UW-40 and UCS-56.7.

(25)

Table UHA-32-2
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 7

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UHA-32(d)]	
		Up to 2 in. (50 mm)	Over 2 in. (50 mm)
P-No. 7 Gr. Nos. 1, 2	1,350 (730)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

GENERAL NOTES:
(a) Postweld heat treatment is not required when conditions (1) through (4) below are met.
(1) vessels are constructed of alloy UNS S40500, alloy UNS S41003, or alloy UNS S41008
(2) vessels have a carbon content not exceeding 0.08%
(3) vessels are welded with electrodes that produce
(a) an austenitic-chromium-nickel weld deposit or
(b) a non-air-hardening nickel-chromium-iron weld deposit
(4) vessels have a nominal thickness
(a) not exceeding $^3/_8$ in. (10 mm) or
(b) exceeding $^3/_8$ in. (10 mm) but not greater than $1^1/_2$ in. (38 mm) for full-penetration welds in butt joints when
(-1) a preheat of 450°F (230°C) is maintained during welding and
(-2) the joints are completely radiographed
(b) Postweld heat treatment shall be performed as prescribed in UW-40 and UCS-56.7 except that the cooling rate shall be a maximum of 100°F/hr (56°C/h) in the range above 1,200°F (650°C) after which the cooling rate shall be sufficiently rapid to prevent embrittlement.
(c) The following alloys are exempt from PWHT: UNS Nos. S40910, S40920, S40930, S40935, S40936, S40945, S40975, S40977, S43035, S43036, S43932, S43940, and S44400.

Table UHA-32-3
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 8

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UHA-32(d)]
P-No. 8 Gr. Nos. 1, 2, 3, 4	...	...

GENERAL NOTES:
(a) Postweld heat treatment is neither required nor prohibited for joints between austenitic stainless steels of the P-No. 8 group. See Nonmandatory Appendix UHA-A.
(b) If postweld heat treatment is performed for P-No. 8 materials, the Manufacturer shall consider the steps necessary to avoid embrittlement, sensitization, and the precipitation of deleterious phases. See Section II, Part D, Nonmandatory Appendix A, A-207 through A-210.

Table UHA-32-4
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 10H

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UHA-32(d)]
P-No. 10H Gr. No. 1	...	...

GENERAL NOTE: For the austenitic-ferritic wrought or cast duplex stainless steels listed below, postweld heat treatment is neither required nor prohibited, but any heat treatment applied shall be performed as listed below and followed by liquid quenching or rapid cooling by other means:

Alloy	Postweld Heat Treatment Temperature, °F (°C)
J93345	2,050 min. (1 120 min.)
J93380	2,010 min. (1 100 min.)
S31200, S31803, and S32550	1,900 min. (1 040 min.)
S31260	1,870–2,010 (1 020–1 100)
S31500	1,785–1,875 (975–1 025)
S32101	1,870 min. (1 020 min.)
S32202	1,800–1,975 (980–1 080)
S32205	1,870–2,010 (1 020–1 100)
S32304	1,800 min. (980 min.)
S32750	1,880–2,060 (1 025–1 125)
S32760	2,010–2,085 (1 100–1 140)
S32900 (0.08 max. C)	1,725–1,775 (940–970)
S32950	1,825–1,875 (995–1 025)
S39274	1,925–2,100 (1 050–1 150)

(25)

Table UHA-32-5
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 10

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UHA-32(d)]
P-No. 10I Gr. No. 1	1,350 (730)	1 hr/in. (25 mm), 15 min minimum

GENERAL NOTES:

(a) Postweld heat treatment shall be performed as prescribed in UW-40 and UCS-56.7 except that the cooling rate shall be a maximum of 100°F/hr (56°C/h) in the range above 1,200°F (650°C) after which the cooling rate shall be rapid to prevent embrittlement.

(b) Postweld heat treatment is neither required nor prohibited for a thickness of $^1/_2$ in. (13 mm) or less.

(c) For Alloy S44635, the rules for ferritic chromium stainless steel shall apply, except that postweld heat treatment is neither prohibited nor required. If heat treatment is performed after forming or welding, it shall be performed at 1,850°F (1010°C) minimum followed by rapid cooling to below 800°F (430°C).

Table UHA-32-6
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 10K

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UHA-32(d)]
P-No. 10K Gr. No. 1	...	...

GENERAL NOTE: For Alloy S44660, the rules for ferritic chromium stainless steel shall apply, except that postweld heat treatment is neither required nor prohibited. If heat treatment is performed after forming or welding, it shall be performed at 1,500°F to 1,950°F (816°C to 1 066°C) for a period not to exceed 10 min followed by rapid cooling.

Table UHA-32-7
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 45

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UHA-32(d)]
P-No. 45	...	...

GENERAL NOTES:
(a) Postweld heat treatment is neither required nor prohibited for joints between austenitic stainless steels of the P-No. 45 group, but any heat treatment applied shall be performed as listed below and followed by liquid quenching or rapid cooling by other means:

Alloy	Postweld Heat Treatment Temperature, °F (°C)
S31266	2,085–2,318 (1 140–1 170)

(b) If postweld heat treatment is performed for P-No. 45 materials, the Manufacturer shall consider the steps necessary to avoid embrittlement, sensitization, and the precipitation of deleterious phases. See Section II, Part D, Nonmandatory Appendix A, A-207 through A-210.

UHA-33 RADIOGRAPHIC EXAMINATION

(a) The requirements for radiographing prescribed in UW-11, UW-51, and UW-52 shall apply in high alloy vessels, except as provided in (b) below. (See UHA-21.)

(b) Butt-welded joints in vessels constructed of materials conforming to Type 405 welded with straight chromium electrodes, and to Types 410, 429, and 430 welded with any electrode, shall be radiographed in all thicknesses. The final radiographs of all straight chromium ferritic welds including major repairs to these welds shall be made after postweld heat treatment has been performed.

(c) Butt-welded joints in vessels constructed of austenitic chromium–nickel stainless steels which are radiographed because of the thickness requirements of UW-11, or for lesser thicknesses where the joint efficiency reflects the credit for radiographic examination of Table UW-12, shall be radiographed following post heating if such is performed.

UHA-34 LIQUID PENETRANT EXAMINATION

All austenitic chromium–nickel alloy steel and austenitic/ferritic duplex steel welds, both groove and fillet, that exceed a nominal size of $^3/_4$ in. (19 mm), as defined in UW-40.6, and all martensitic chromium steel welds shall be examined for the detection of cracks by the liquid penetrant method. This examination shall be made following heat treatment if heat treatment is performed. All cracks shall be eliminated.

FABRICATION

UHA-40 GENERAL (25)

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of high alloy steel and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsections B and D.

For UNS S17400, no welding is permitted except nonpressure parts may be welded to the pressure vessel provided the following requirements are met:

(a) Prior to welding, all material shall be heat treated to the solution-annealed condition or to a yield strength of 105 ksi (724 MPa) or less in accordance with the heat treatment requirements of the applicable material specification.

(b) The weld metal shall be the same nominal composition as UNS S17400.

(c) After welding, the welded component shall be fully solution annealed and aged to the H1075, H1100, or H1150 condition, as applicable.

(d) The weldment shall be liquid penetrant examined per Mandatory Appendix 8 after final heat treatment.

(e) Separate welding procedure and performance qualification in accordance with Section IX shall be conducted.

(f) Temporary welds and repair welds shall be considered the same as all other welds insofar as requirements for qualified operators and procedures and for heat treatment are concerned.

(25) UHA-42 WELD METAL COMPOSITION

Welds that are exposed to the corrosive action of the contents of the vessel should have a resistance to corrosion that is not substantially less than that of the base metal. The use of filler metal that will deposit weld metal with practically the same composition as the material joined is recommended. When the manufacturer is of the opinion that a physically better joint can be made by departure from these limits, filler metal of a different composition may be used provided the strength of the weld metal at the operating temperature is not appreciably less than that of the high alloy material to be welded, and the user is satisfied that its resistance to corrosion is satisfactory for the intended service. The columbium content of weld metal shall not exceed 1.00% for design temperatures above 900°F (482°C).

UHA-44 REQUIREMENTS FOR POSTFABRICATION HEAT TREATMENT DUE TO STRAINING

(a) The following rules shall apply in addition to general rules for forming given in UHA-40.

(1) If the following conditions prevail, the cold formed areas of pressure-retaining components manufactured of austenitic alloys shall be solution annealed by heating at the temperatures given in Table UHA-44 for 20 min/in. (20 min/25 mm) of thickness followed by rapid cooling:

(-a) the finishing-forming temperature is below the minimum heat-treating temperature given in Table UHA-44; and

(-b) the design metal temperature and the forming strains exceed the limits shown in Table UHA-44.

(2) Forming strains shall be determined by the equations in Table UG-79-1.

(b) When forming strains cannot be calculated as shown in (a) above, the Manufacturer shall have the responsibility to determine the maximum forming strain. For flares, swages, or upsets, heat treatment in accordance with Table UHA-44 shall apply, regardless of the amount of strain.

INSPECTION AND TESTS

UHA-50 GENERAL (25)

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are constructed of high alloy steel and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsections B and D.

UHA-51 IMPACT TESTS (25)

Except as exempted in (g), impact tests shall be performed on materials listed in Table UHA-23 as prescribed in (a) for all combinations of materials and minimum design metal temperatures (MDMTs) and for UNS S17400 materials.

Nonmandatory Appendix JJ, Figures JJ-1.2-1 through JJ-1.2-5 provide flowchart illustrations of impact testing requirements.

(a) Requirements for Impact Testing of Base Metal, Heat-Affected Zones, and Weld Metal. Impact tests shall be made from sets of three specimens removed from each of the base metals, the heat-affected zones (HAZs), and the weld metal. Specimens shall be subjected to the same thermal treatments[54] as the part or vessel that the specimens represent. Test procedures, size, location, and orientation of the specimens shall be as required in UG-84.

(1) When the MDMT Is −320°F (−196°C) and Warmer. Impact test temperature shall be no warmer than the MDMT. The following requirements shall be met:

(-a) All specimens in a set shall achieve a lateral expansion opposite the notch not less than 0.015 in. (0.38 mm).

(-b) If the requirements of (-a) are not met, a retest of three additional specimens removed from the same test coupon is permitted when both of the following conditions are met:

(-1) The average value of the three specimens equals or exceeds 0.015 in. (0.38 mm).

(-2) The value of lateral expansion for one specimen of a set is less than 0.015 in. (0.38 mm) but not less than 0.010 in. (0.25 mm).

Each retest specimen shall meet the requirements of (-a).

(-c) If the requirements of (-b) are not met, the material may be reheat treated. After reheat treatment, new sets of specimens shall be made and retested; all specimens shall meet the requirements of (-a).

(2) When the MDMT Is Colder Than −320°F (−196°C). The following impact tests or ASTM E1820 J_{IC} tests shall be performed:

(-a) Production welding processes shall be limited to

(-1) shielded metal arc welding (SMAW)

(-2) flux cored arc welding (FCAW)

(-3) gas metal arc welding (GMAW)

Table UHA-44
Postfabrication Strain Limits and Required Heat Treatment

Grade	UNS Number	Limitations in Lower Temperature Range: For Design Temperature, °F (°C) Exceeding	Limitations in Lower Temperature Range: For Design Temperature, °F (°C) But Less Than or Equal to	Limitations in Lower Temperature Range: And Forming Strains Exceeding, %	Limitations in Higher Temperature Range: For Design Temperature, °F (°C), Exceeding	Limitations in Higher Temperature Range: And Forming Strains Exceeding, %	Minimum Heat-Treatment Temperature, °F (°C), When Design Temperature and Forming Strain Limits Are Exceeded [Note (1)] and [Note (2)]
201-1	S20100 heads	All	All	All	All	All	1,950 (1 065)
201-1	S20100 all others	All	All	4	All	4	1,950 (1 065)
201-2	S20100 heads	All	All	All	All	All	1,950 (1 065)
201-2	S20100 all others	All	All	4	All	4	1,950 (1 065)
201LN	S20153 heads	All	All	All	All	All	1,950 (1 065)
201LN	S20153 all others	All	All	4	All	4	1,950 (1 065)
204	S20400 heads	All	All	All	All	All	1,950 (1 065)
204	S20400 all others	All	All	4	All	4	1,950 (1 065)
304	S30400	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
304H	S30409	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
304L	S30403	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
304N	S30451	1,075 (580)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
309S	S30908	1,075 (580)	1,250 (675)	20	1,250 (675)	10	2,000 (1 095)
310H	S31009	1,075 (580)	1,250 (675)	20	1,250 (675)	10	2,000 (1 095)
310S	S31008	1,075 (580)	1,250 (675)	20	1,250 (675)	10	2,000 (1 095)
316	S31600	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
316H	S31609	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
316N	S31651	1,075 (580)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
321	S32100	1,000 (540)	1,250 (675)	15 [Note (3)]	1,250 (675)	10	1,900 (1 040)
321H	S32109	1,000 (540)	1,250 (675)	15 [Note (3)]	1,250 (675)	10	2,000 (1 095)
347	S34700	1,000 (540)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
347H	S34709	1,000 (540)	1,250 (675)	15	1,250 (675)	10	2,000 (1 095)
347LN	S34751	1,000 (540)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
348	S34800	1,000 (540)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
348H	S34809	1,000 (540)	1,250 (675)	15	1,250 (675)	10	2,000 (1 095)

GENERAL NOTES:
(a) The limits shown are for cylinders formed from plates, spherical or dished heads formed from plate, and tube and pipe bends.
(b) When the forming strains cannot be calculated as shown in UHA-44(a), the forming strain limits shall be half those tabulated in this Table [see UHA-44(b)].

NOTES:
(1) Rate of cooling from heat-treatment temperature is not subject to specific control limits.
(2) While minimum heat-treatment temperatures are specified, it is recommended that the heat-treatment temperature range be limited to 150°F (85°C) above that minimum [250°F (140°C) for 347, 347H, 347LN, 348, and 348H].
(3) For simple bends of tubes or pipes whose outside diameter is less than 3.5 in. (88 mm), this limit is 20%.

(-4) submerged arc welding (SAW)

(-5) plasma arc welding (PAW)

(-6) gas tungsten arc welding (GTAW)

(-7) diffusion welding (DFW)

(-b) For weld consumables, each heat, lot, or batch of filler metal and filler metal and flux combination shall be pre-use tested as required by (d)(4)(-a) through (d)(4)(-c). Exemption from pre-use testing required by (d)(4)(-d) and (d)(4)(-e) is not permitted.

(-c) Toughness testing shall be performed as specified in (-1) through (-3), as appropriate.

(-1) If using Type 316L or Type 308L weld filler metal welded with the GTAW, FCAW, or GMAW processes

(+a) weld metal deposited from each heat of

(+1) Type 316L filler metal shall have a ferrite number (FN) not greater than 10

(+2) Type 308L filler metal shall have an FN in the range of 4 to 14

NOTE: Ferrite numbers shall be measured by a ferritescope or magna gage calibrated in accordance with AWS A4.2 or as determined by applying the chemical composition from the test weld to Figure UHA-51-1.

(+b) impact tests shall be conducted at −320°F (−196°C) on three sets of test specimens: one set each from the base metal, the weld metal, and the HAZ.

(+c) each specimen shall have a lateral expansion opposite the notch not less than 0.021 in. (0.53 mm).

(-2) If using weld filler metal material type or welding processes other than those specified in (-1)

(+a) weld metal deposited from each heat or lot of austenitic stainless steel filler metal used in production shall have an FN not greater than the FN determined for the test weld.

(+b) impact tests shall be conducted at −320°F (−196°C) on a set of three test specimens from the base metal.

(+c) each specimen shall meet (-1)(+c).

(+d) ASTM E1820 J_{IC} tests shall be conducted on two sets of two specimens, one set each from the HAZ and the weld metal, at a test temperature not warmer than the MDMT. The HAZ specimen orientation shall be T-L. A $K_{IC}(J)$ value of not less than $120\text{ksi}\sqrt{\text{in.}}$ $\left(132\text{ MPa}\sqrt{\text{m}}\right)$ is required for all specimens tested.

(-3) If the welding process is DFW, the following requirements shall apply:

(+a) Welding procedure qualification shall include impact test of welds.

(+b) Two sets of three impact test specimens in accordance with UG-84(c) shall be taken from the test block for procedure qualification described in QW-185 of Section IX. One set is perpendicular to the interface planes and the other is parallel to the interface planes.

(+c) Impact test shall be performed at −320°F (−196°C) and each of the three specimens from each test set shall have a lateral expansion opposite the notch no less than 0.021 in. (0.53 mm).

(-4) When the required Charpy impact test specimens do not meet the lateral expansion requirements in (-1)(+c)

(+a) ASTM E1820 J_{IC} tests shall be conducted on an additional set of two specimens representing the failed set of impact test specimens at a test temperature no warmer than MDMT.

(+b) The specimen orientation for the base metal and HAZ shall be T-L.

(+c) A $K_{IC}(J)$ value of not less than $120\text{ksi}\sqrt{\text{in.}}$ $\left(132\text{ MPa}\sqrt{\text{m}}\right)$ is required for all specimens tested.

(b) Required Impact Testing for Welding Procedure Qualifications. When the rules of this Division require impact testing of any of the components[55] of the welded joint, the welding procedure qualification test coupons shall be impact tested in accordance with (a) and UG-84(h).

(c) Required Impact Testing When Thermal Treatments Are Performed. Impact tests at the required test temperature in accordance with (a) but not warmer than 70°F (20°C) are required whenever thermal treatments[54] are applied to the following materials within the temperature ranges listed in (1) through (4):

(1) austenitic stainless steels between 900°F and 1,650°F (480°C and 900°C) except Types 304, 304L, 316, and 316L between 900°F and 1,300°F (480°C and 705°C) are exempt from impact testing when both of the following conditions apply:

(-a) The MDMT is −20°F (−29°C) or warmer.

(-b) Production impact tests of the thermally treated weld metal are performed for Category A and B joints.

(2) austenitic-ferritic duplex stainless steels between 600°F and 1,750°F (315°C and 955°C)

(3) ferritic chromium stainless steels between 800°F and 1,350°F (425°C and 730°C)

(4) martensitic chromium stainless steels between 800°F and 1,350°F (425°C and 730°C)

(d) Required Impact Testing for Austenitic Stainless Steel Welding Consumables With MDMTs Colder Than −155°F (−104°C). All of the following conditions shall be satisfied:

(1) The welding processes are limited to SMAW, SAW, FCAW, GMAW, GTAW, and PAW.

(2) The applicable Welding Procedure Specifications (WPSs) are supported by Procedure Qualification Records (PQRs) either

(-a) with impact testing in accordance with the requirements of (a)

(-b) without impact testing when exempted by other provisions of this Division

(3) The base metal and weld filler metal (for welds produced with or without filler metal) have a carbon content not exceeding 0.10%, except when using SFA-5.9 ER310 or SFA-5.4 E310-15 or E310-16 [see (f) and (g)(4)].

(4) Weld metal produced by filler metals conforming to SFA-5.4, SFA-5.9, SFA-5.11, SFA-5.14, and SFA-5.22 as modified below shall be pre-use tested.

(-a) The weld metal deposited by each heat of filler metal or each combination of heat of filler metal and lot of flux using the welding process specified in (1) shall be impact tested in accordance with the requirements of (a). Test coupons shall be prepared in accordance with Section II, Part C, SFA-5.4, A9.3.5, except the impact testing shall be in accordance with UG-84(g) for weld metal only.

(-b) Combining more than one welding process or more than one heat or lot of welding filler metals into a single test coupon is prohibited.

(-c) Testing in accordance with the requirements of (a) may be conducted by the welding consumable manufacturer in accordance with Section II, Part C, SFA-5.4, A9.3.5. Test results shall be reported on heat- or lot-specific mill test reports.

(-d) Filler metals ENiCrFe-2, ENiCrFe-3, ENiCrMo-3, ENiCrMo-4, ENiCrMo-6, ERNiCr-3, ERNiCrMo-3, ERNiCrMo-4, SFA-5.4 E310-15 or 16 are exempt from pre-use testing under both the following conditions:

(-1) The procedure qualification impact testing in accordance with UG-84(h) is at the MDMT or colder.

(-2) Welding is performed using filler metal of the same manufacturer brand and type as used in the procedure qualification.

(-e) When procedure qualification impact testing is performed in accordance with UG-84(h) at the MDMT or colder, pre-use testing is not required for each heat of ER308L, ER316L, and ER310 used with the GTAW or PAW processes.

(e) Production Impact Tests

(1) Unless otherwise exempted by the rules of this Division, when the Weld Procedure Qualification requires impact testing, production impact tests in accordance with UG-84(i) are required for welded vessels constructed of any of the following:

(-a) duplex stainless steels

(-b) ferritic stainless steels

(-c) martensitic stainless steels

(2) Unless exempted in (g)(5)(-a) or (g)(-5)(-b), production impact tests in accordance with UG-84(i) are required for vessels constructed of austenitic stainless steels.

At MDMTs colder than −320°F (−196°C), vessel (i.e., production) impact tests or ASTM E1820 J_{IC} tests shall be conducted in accordance with (a)(2).

(f) Production Impact Tests for Autogenous Welds in Austenitic Stainless Steels. Vessel (production) impact tests are required for autogenous welds (i.e., welds without filler metal) in austenitic stainless steel vessels unless exempted by (g)(5)(-c).

(g) Exemptions From Impact Testing

(1) Thin Materials. Impact tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm).

(2) Low Stress. Except as modified by (c), when the coincident ratio of design stress[56] in tension to allowable tensile stress is less than 0.35, it is not required to impact test materials listed in Table UHA-23. This exemption also applies to the welding procedures and production welds for the component.

(3) Base Metals and HAZs. For Table UHA-23 base metals, impact testing is not required for the following combinations of base metals and HAZs (when welded) and MDMTs, except as modified in (c):

(-a) austenitic chromium–nickel stainless steels as follows:

(-1) having a carbon content not exceeding 0.10% at MDMTs of −320°F (−196°C) and warmer

(-2) having carbon content exceeding 0.10% at MDMTs of −55°F (−48°C) and warmer

(-3) for castings at MDMTs of −20°F (−29°C) and warmer

(-b) austenitic chromium–manganese–nickel stainless steels (200 series) as follows:

(-1) having a carbon content not exceeding 0.10% at MDMTs of −320°F (−196°C) and warmer

(-2) having a carbon content exceeding 0.10% at MDMTs of −55°F (−48°C) and warmer

(-3) for castings at MDMTs of −20°F (−29°C) and warmer

(-c) the following steels in all product forms at MDMTs of −20°F (−29°C) and warmer:

(-1) austenitic ferritic duplex steels with a nominal material thickness of $^3/_8$ in. (10 mm) and thinner

(-2) ferritic chromium stainless steels with a nominal material thickness of $^1/_8$ in. (3 mm) and thinner

(-3) martensitic chromium stainless steels with a nominal material thickness of $^1/_4$ in. (6 mm) and thinner

(-d) SA-453 Grade 660, Classes A and B at MDMTs of −320°F (−196°C) and warmer

(4) Welding Procedure Qualifications. For the following combinations of weld metals and MDMTs, impact testing for welding procedure qualifications is not required except as specified in (c):

(-a) austenitic chromium–nickel stainless steel base materials having a carbon content not exceeding 0.10% welded without the addition of filler metal at MDMTs of −155°F (−104°C) and warmer

(-b) austenitic weld filler metal

(-1) having a carbon content not exceeding 0.10% and conforming to SFA-5.4, SFA-5.9, SFA-5.11, SFA-5.14, or SFA-5.22 at MDMTs of −155°F (−104°C) and warmer;

(-2) having a carbon content exceeding 0.10% and conforming to SFA-5.4, SFA-5.9, SFA-5.11, SFA-5.14, or SFA-5.22 at MDMTs of −55°F (−48°C) and warmer;

(-c) the following weld filler metals, when the base metal of nominally matching composition is exempt as stated in (3)(-c), then the weld metal shall also be exempt at MDMTs of −20 (−29°C) and warmer

(-1) austenitic ferritic duplex steels

(-2) ferritic chromium stainless steels

(-3) martensitic chromium stainless steels

(5) Production Impact Tests for Austenitic Stainless Steels

(-a) At MDMTs of −155°F (−104°C) and warmer, production impact tests are not required when the impact test exemption requirements for the applicable welding procedure qualification in (4) are satisfied.

(-b) At MDMTs between −155°F and −320°F (−104°C and −196°C) production impact tests are not required when the pre-use test requirements in (d) are satisfied.

(-c) For autogenous welds (i.e., welded without filler metal) in austenitic stainless steels, production impact tests are not required when both of the following conditions are satisfied:

(-1) The material is solution annealed after welding.

(-2) The MDMT is not colder than −320°F (−196°C).

(h) Definitions

(1) "Nominal Thickness" as Used in (g)(3)(-c). The nominal thickness of plates and pipes as defined in Mandatory Appendix 3 shall be used for determining the nominal material thickness for toughness requirements. For other product forms, the nominal material thickness shall be determined as follows:

(-a) for castings, maximum thickness between two cast coincidental surfaces

(-b) for hollow cylindrical forgings, maximum radial thickness

(-c) for disk forgings, maximum thickness, including the length of an integral hub if a hub is present

(-d) for weld neck flanges, the larger of the thickness of the flange ring or the neck

(2) "Carbon Content" as Used in (g)(3)(-a) and (g)(3)(-b). Carbon content is as specified by the purchaser and shall be within the limits of the material specification.

UHA-52 WELDED TEST PLATES

(a) For welded vessels constructed of Type 405 material which are not postweld heat treated, welded test plates shall be made to include material from each melt of plate steel used in the vessel. Plates from two different melts may be welded together and be represented by a single test plate.

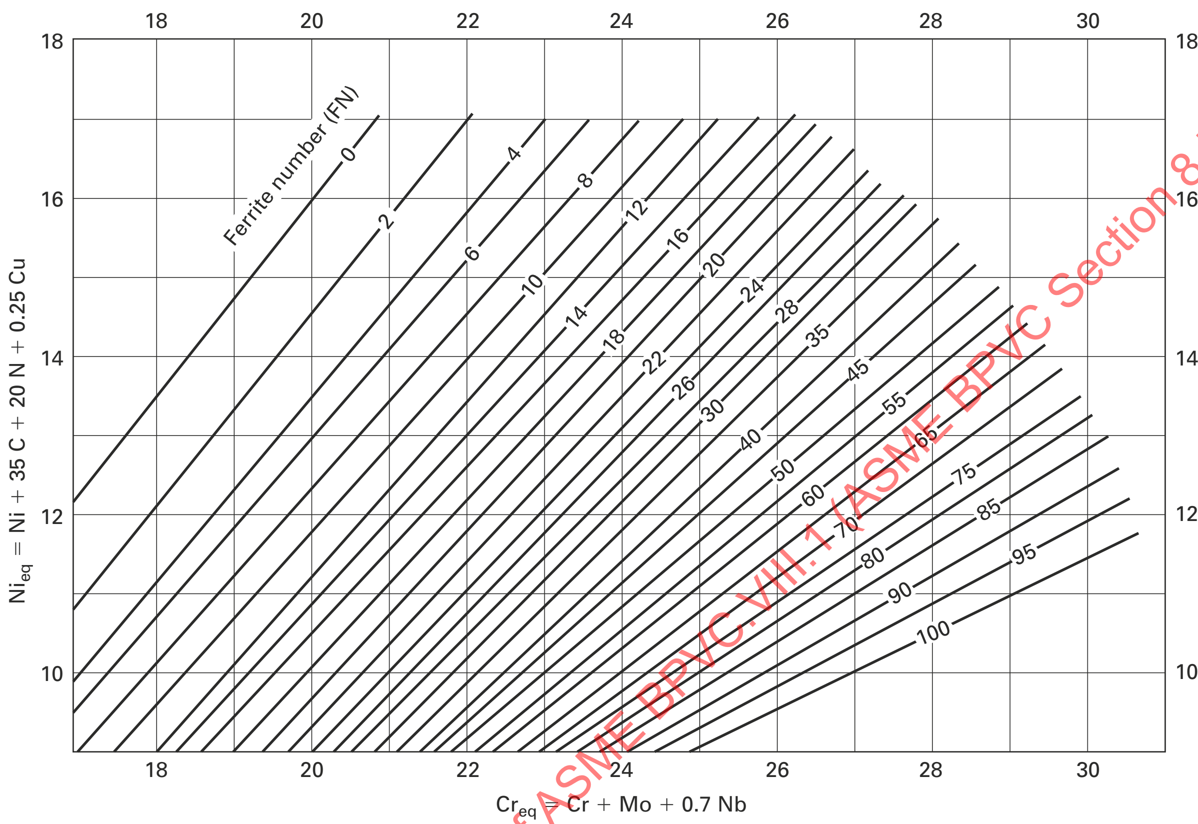
(b) From each welded test plate there shall be taken two face-bend test specimens as prescribed in Section IX, Figure QW-462.3(a) or Figure QW-462.3(b), as applicable; these shall meet the requirements of Section IX, QW-160.

MARKING AND REPORTS

UHA-60 GENERAL

The provisions for marking and reports in UG-115 through UG-120 shall apply without supplement to vessels constructed of high alloy steels.

Figure UHA-51-1
Weld Metal Delta Ferrite Content



GENERAL NOTES:

(a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:

(1) GMAW welds — 0.08%, except that when self-shielding flux cored electrodes are used — 0.12%

(2) Welds made using other processes — 0.06%.

(b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

NONMANDATORY APPENDIX UHA-A SUGGESTIONS ON THE SELECTION AND TREATMENT OF AUSTENITIC CHROMIUM–NICKEL AND FERRITIC AND MARTENSITIC HIGH CHROMIUM STEELS

(Informative)

UHA-A-1 GENERAL

The selection of the proper metal composition to resist a given corrosive medium and the choice of the proper heat treatment and surface preparation of the material selected are not within the scope of this Division. Section II, Part D, Nonmandatory Appendix A discusses some of the factors that should be considered in arriving at a proper selection.

UHA-A-2 DISSIMILAR WELD METAL

The difference between the coefficients of expansion of the base material and the weld should receive careful consideration before undertaking the welding of ferritic type stainless steels with austenitic electrodes for services involving severe temperature conditions, particularly those of a cyclic nature.

UHA-A-3 FABRICATION

It is recommended that the user of austenitic chromium–nickel steel vessels in corrosive service consider the following additional fabrication test.

A welded guided-bend test specimen should be made as prescribed in Section IX, QW-161.2 from one of the heats of material used in the shell. The test plate should be welded by the procedure used in the longitudinal joints of the vessel and should be heat treated using the same temperature cycle as used for the vessel. The operations on the test plate should be such as to duplicate as closely as possible the physical conditions of the material in the vessel itself.

Grind and polish the specimen and immerse it for not less than 72 hr in a boiling solution consisting of 47 ml concentrated sulfuric acid and 13 g of crystalline copper sulfate ($CuSO_4 \cdot 5H_2O$) per liter of water. Then bend the specimen so as to produce an elongation of not less than 20% at a section in the base metal $^1/_4$ in. (6 mm) from the edge of the weld. The metal shall show no sign of disintegration after bending.

UHA-A-4 RELAXATION CRACKING (25)

Relaxation cracking[57] can occur in P-No. 8 materials not only in cold-formed areas but also in welds where high-level residual tensile stress exists. Unless one or more of the following conditions are satisfied, PWHT at the temperature listed in Table UHA-44 for the specific material grade may be advisable to avoid relaxation cracking:

(a) The design temperature does not exceed 1,000°F (540°C).

(b) The welding is limited to the following (singularly or in combination):

(1) circumferential butt welds in pressure parts with a nominal base metal thickness of $^1/_2$ in. (13 mm) or less at the weld.

(2) circumferential fillet welds with a throat thickness of $^1/_2$ in. (13 mm) or less, and combination groove and fillet welds with a weld thickness of $^1/_2$ in. (13 mm) or less.

(3) attaching extended heat-absorbing fins to pipe and tube materials by electric resistance welding, provided the following requirements are met:

(-a) a maximum pipe or tube size of NPS 4 (DN 100)

(-b) a maximum specified carbon content (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits) of not more that 0.15%

(-c) a maximum fin thickness of $^1/_8$ in. (3 mm)

In addition, prior to using the welding procedure, the Manufacturer shall demonstrate that the heat-affected zone does not encroach upon the minimum wall thickness.

(4) attaching non-load-carrying studs not exceeding $^1/_2$ in. (13 mm) in diameter when using an automatic arc stud welding or automatic resistance stud welding process.

(5) attaching bare-wire thermocouples by capacitor discharge welding or electric resistance welding under the requirements of UCS-56.8 with a nominal base metal thickness not less than 0.2 in. (5 mm).

PART UCI
REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF CAST IRON

GENERAL

UCI-1 SCOPE

The rules in Part UCI are applicable to pressure vessels and vessel parts that are constructed of cast iron, cast nodular iron having an elongation of less than 15% in 2 in. (50 mm), or of cast dual metal (see UCI-23 and UCI-29) except standard pressure parts covered by UG-11(b), and shall be used in conjunction with the general requirements in Subsection A insofar as these requirements are applicable to cast material.

UCI-2 SERVICE RESTRICTIONS

Cast iron vessels shall not be used for services as follows:

(a) to contain lethal[58] or flammable substances, either liquid or gaseous

(b) for unfired steam boilers [see U-1(g)(1)]

(c) for direct firing [see UW-2(d)]

UCI-3 PRESSURE–TEMPERATURE LIMITATIONS

(a) The design pressure for vessels and vessel parts constructed of any of the classes of cast iron listed in Table UCI-23 shall not exceed the following values except as provided in (b) and (c) below:

(1) 160 psi (1.1 MPa) at temperatures not greater than 450°F (230°C) for vessels containing gases, steam, or other vapors;

(2) 160 psi (1.1 MPa) at temperatures not greater than 375°F (190°C) for vessels containing liquids;

(3) 250 psi (1.7 MPa) for liquids at temperatures less than their boiling point at design pressure, but in no case at temperatures exceeding 120°F (50°C);

(4) 300 psi (2 MPa) at temperatures not greater than 450°F (230°C) for bolted heads, covers, or closures that do not form a major component of the pressure vessel.

(b) Vessels and vessel parts constructed of stress relieved material conforming to Classes 40 through 60 of SA-278 may be used for design pressures up to 250 psi (1.7 MPa) at temperatures up to 650°F (345°C), provided the distribution of metal in the pressure-containing walls of the casting is shown to be approximately uniform.

(c) Vessels and vessel parts constructed of stress relieved material conforming to SA-476 may be used for design pressures up to 250 psi (1.7 MPa) at temperatures up to 450°F (230°C).

(d) Cast iron flanges and flanged fittings conforming to ASME B16.1, Cast Iron Pipe Flanges and Flanged Fittings, Classes 125 and 250, may be used in whole or in part of a pressure vessel for pressures not exceeding the American National Standard ratings at temperatures not exceeding 450°F (230°C).

MATERIALS

UCI-5 GENERAL

All cast iron material subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table UCI-23 except as otherwise provided in UG-11.

UCI-12 BOLT MATERIALS

The requirements for bolts, nuts, and washers shall be the same as for carbon and low alloy steels in UCS-10 and UCS-11.

DESIGN

UCI-16 GENERAL

The rules in the following paragraphs apply specifically to the design of pressure vessels and pressure vessel parts of cast iron and shall be used in conjunction with the general requirements for *Design* in Subsection A, insofar as these requirements are applicable to cast materials.

For components for which the Code provides no design rules, the provisions of UG-19(b) and UG-19(c) apply. If a proof test is performed, the rules of UCI-101 apply.

UCI-23 MAXIMUM ALLOWABLE STRESS VALUES

(a) Table UCI-23 gives the maximum allowable stress values in tension at the temperatures indicated for castings conforming to the specifications listed therein. For dual metal cylinders conforming to SA-667 or SA-748, the maximum calculated stress, including all applicable loadings of UG-22, shall not exceed the allowable stress given in Table UCI-23 computed on the basis of the gray cast iron thickness of the cylinder.

(b) The maximum allowable stress value in bending shall be $1\frac{1}{2}$ times that permitted in tension, and the maximum allowable stress value in compression shall be two times that permitted in tension.

(25)

Table UCI-23
Maximum Allowable Stress Values in Tension for Cast Iron

Spec. No.	Class/Type	Specified Min. Tensile Strength, ksi (MPa)	Maximum Allowable Stress, ksi (MPa), for Metal Temperature Not Exceeding		Ext. Press. Chart Figure No. [Note (1)]
			450°F (230°C) and Colder	650°F (345°C)	
SA-667	...	20 (138)	2.0 (13.8)	...	CI-1
SA-278	20	20 (138)	2.0 (13.8)	...	CI-1
SA-278	25	25 (172)	2.5 (17.2)	...	CI-1
SA-278	30	30 (207)	3.0 (20.7)	...	CI-1
SA-278	35	35 (241)	3.5 (24.1)	...	CI-1
SA-278	40	40 (276)	4.0 (27.6)	4.0 (27.6)	CI-1
SA-278	45	45 (310)	4.5 (31.0)	4.5 (31.0)	CI-1
SA-278	50	50 (345)	5.0 (34.5)	5.0 (34.5)	CI-1
SA-439	D-2	58 (400)	5.4 (37.2)	...	CI-1
SA-47	(Grade 3-2510)	50 (345)	5.0 (34.5)	5.0 (34.5)	CI-1
SA-278	55	55 (379)	5.5 (37.9)	5.5 (37.9)	CI-1
SA-278	60	60 (414)	6.0 (41.4)	6.0 (41.4)	CI-1
SA-476	...	80 (552)	8.0 (55.2)	...	CI-1
SA-748	20	16 (110)	1.6 (11.0)	...	CI-1
SA-748	25	20 (138)	2.0 (13.8)	...	CI-1
SA-748	30	24 (165)	2.4 (16.5)	...	CI-1
SA-748	35	28 (193)	2.8 (19.3)	...	CI-1

NOTE:
(1) Figure CI-1 is contained in Section II, Part D, Subpart 3.

UCI-28 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figures in Section II, Part D, Subpart 3 and the temperature limits of UG-20(c).

UCI-29 DUAL METAL CYLINDERS

The minimum wall thickness of dual metal cylinders conforming to SA-667 or SA-748 shall be 5 in. (125 mm), and the outside diameter of such cylinders shall not exceed 36 in. (900 mm).

UCI-32 HEADS WITH PRESSURE ON CONCAVE SIDE

Heads with pressure on the concave side (plus heads) shall be designed in accordance with the equations in UG-32 using the maximum allowable stress value in tension.

UCI-33 HEADS WITH PRESSURE ON CONVEX SIDE

The thickness of heads with pressure on the convex side (minus heads) shall not be less than the thickness required in UCI-32 for plus heads under the same pressure nor less than 0.01 times the inside diameter of the head skirt.

UCI-35 SPHERICALLY SHAPED COVERS (HEADS) (25)

(a) Circular cast iron spherically shaped heads with bolting flanges, similar to Figure 1-6, sketches (b), (c), and (d), shall be designed in accordance with the provisions in 1-6, except that corners and fillets shall comply with the requirements of UCI-37.

(b) Circular cast iron spherically shaped heads with bolting flanges other than those described in (a) above shall be designed in accordance with the following requirements.

(1) The head thickness shall be determined in accordance with the requirements in UG-32.

(2) The spherical and knuckle radii shall conform to the requirements in UG-32.

(c) Cast iron flanges and flanged fittings conforming to ASME B16.1 [see UG-44(a)(1)] may be used in whole or in part of a pressure vessel for pressures not exceeding American National Standard ratings at temperatures not exceeding 450°F (232°C).

(d) The longitudinal hub stress, S_H, for flanges designed in accordance with Mandatory Appendix 1, 1-6 and Mandatory Appendix 2 shall not be greater than the maximum allowable stress in tension for cast iron from Table UCI-23.[59]

UCI-36 OPENINGS AND REINFORCEMENTS

(a) The dimensional requirements in UG-36 through UG-46 are applicable to cast iron and shall be used in the design of openings and reinforcements in pressure vessels and pressure vessel parts which are cast integrally with the vessel or vessel part. In no case shall the thickness of the reinforcement, including the nominal thickness of the vessel wall, exceed twice the nominal thickness of the vessel wall.

(b) Cast iron flanges, nozzles, and openings shall not be attached to steel or nonferrous pressure vessels or pressure parts by welding or brazing, nor shall they be considered to contribute strength to the vessel or part.

UCI-37 CORNERS AND FILLETS

A liberal radius shall be provided at projecting edges and in reentrant corners in accordance with good foundry practice. Abrupt changes in surface contour and in wall thickness at junctures shall be avoided. Fillets shall conform to the following.

Fillets forming the transition between the pressure-containing walls and integral attachments, such as brackets, lugs, supports, nozzles, flanges, and bosses, shall have a radius not less than one-half the thickness of the pressure-containing wall adjacent to the attachment.

FABRICATION

UCI-75 GENERAL

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts of cast iron and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A insofar as these requirements are applicable to cast materials.

(25) UCI-78 REPAIRS IN CAST IRON MATERIALS

(a) Imperfections that permit leakage in cast iron materials may be repaired by using threaded plugs provided:

(1) the vessel or vessel parts are to operate within the limits of UCI-3(a) or UCI-3(b);

(2) no welding is performed;

(3) the diameter of the plug shall not exceed the diameter of a standard NPS 2 (DN 50) pipe plug;

(4) the plugs, where practical, shall conform in all dimensions to standard NPS (DN) pipe plugs, and in addition they shall have full thread engagement corresponding to the thickness of the repaired section. (See Table UCI-78.1.) Where a tapered plug is impractical because of excess wall thickness in terms of plug diameter and coincident thread engagement, other types of plugs may be used provided both full thread engagement and effective sealing against pressure are obtained. Where possible, the ends of the plug should be ground smooth after installation to conform to the inside and outside contours of the walls of the pressure vessel or pressure part;

Table UCI-78.1 (25)

NPS (DN) Plug or Equivalent	Minimum Thickness of Repaired Section, in. (mm)
1/8 (6)	11/32 (9)
1/4 (8)	7/16 (11)
3/8 (10)	1/2 (13)
1/2 (15)	21/32 (17)
3/4 (20)	3/4 (19)
1 (25)	13/16 (21)
1 1/4 (32)	7/8 (22)
1 1/2 (40)	15/16 (24)
2 (50)	1 (25)

(5) the material from which the plug is manufactured shall conform in all respects to the material specification which applies to the pressure vessel or pressure vessel part;

(6) the machined surface of the drilled or bored hole before tapping shall be free from visible defects and the adjacent metal shown to be sound by radiographic examination;

(7) the thickness of any repaired section in relation to the size of plug used shall not be less than that given in Table UCI-78.1;

(8) the minimum radius of curvature of repaired sections of cylinders or cones in relation to the size of plug used shall not be less than that given in Table UCI-78.2;

(9) the ligament efficiency between any two adjacent plugs shall not be less than 80% where

$$E = \frac{p - \left(\frac{d_1 + d_2}{2}\right)}{p}$$

Table UCI-78.2 (25)

NPS (DN) Plug or Equivalent	Minimum Radius of Curvature of Cylinder or Cone, in. (mm)
1/8 (6)	9/16 (14)
1/4 (8)	11/16 (17)
3/8 (10)	1 1/16 (27)
1/2 (15)	1 1/4 (32)
3/4 (20)	2 (50)
1 (25)	2 1/2 (64)
1 1/4 (32)	4 (100)
1 1/2 (40)	5 1/4 (134)
2 (50)	8 1/8 (207)

where

d_1, d_2 = respective diameters of the two plugs under consideration
E = ligament efficiency
p = distance between plug centers

(10) the pressure vessel or pressure vessel part meets the standard hydrostatic test prescribed in UCI-99.

(b) Surface imperfections, such as undue roughness, which do not permit leakage in cast iron materials may be repaired using driven plugs, provided:

(1) the vessel or vessel parts operate within the limits of UCI-3(a)(1), UCI-3(a)(2), or UCI-3(a)(4);

(2) no welding is performed;

(3) the material from which the plug is manufactured conforms in all respects to the material specification which applies to the pressure vessel or pressure vessel part;

(4) the depth of the plug is not greater than 20% of the thickness of the section and its diameter is not greater than the larger of $^3/_8$ in. (10 mm) or 20% of the thickness of the section;

(5) the pressure vessel or pressure vessel part meets the standard hydrostatic test prescribed in UCI-99.

(c) Surface imperfections, such as undue roughness, which do not permit leakage in cast iron vessels that are to operate under the limits of UCI-3(a)(3) may be repaired under (a) or (b) above or by welding. Where welding is used, the weld and the metal adjacent to it shall be examined by either the magnetic particle or liquid penetrant method and shown to be free of linear indications.

INSPECTION AND TESTS

UCI-90 GENERAL

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts of cast iron and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A insofar as these requirements are applicable to cast material.

UCI-99 STANDARD HYDROSTATIC TEST

(a) Cast iron pressure vessels shall be hydrostatically tested by the method prescribed in UG-99 except that the test pressure shall be two times the maximum allowable working pressure to be marked on the vessel for maximum allowable working pressures greater than 30 psi (200 kPa) and $2^1/_2$ times the maximum allowable working pressure but not to exceed 60 psi (400 kPa) for maximum allowable working pressure under 30 psi (200 kPa).

(b) Cast iron pressure vessels and cast iron pressure vessel parts shall not be painted or otherwise coated either internally or externally prior to the hydrostatic pressure test.

UCI-101 HYDROSTATIC TEST TO DESTRUCTION

(a) The maximum allowable working pressure of identical cast iron vessels or vessel parts, based on testing one of them to destruction, limited to the service conditions specified in UCI-3 and in accordance with UG-101(m) shall be

$$P_R = \frac{P_B}{6.67} \times \frac{(\text{specified minimum tensile strength})}{(\text{avg. tensile strength of test specimens})}$$

where

P_B = destruction test pressure
P_R = maximum allowable working pressure at operating temperatures listed in Table UCI-23

The principle of UG-101(c) shall be followed.

NOTE: It is assumed that failure will occur in bending.

(b) The value of the average tensile strength of test specimens in the foregoing equation shall be determined from the test results of three test bars from the same ladle of iron as used in the part, or from three test specimens cut from the part.

(c) All vessels or vessel parts of the same material, design, and construction, whose maximum allowable working pressure is based on a test to destruction of a sample vessel in accordance with (a) above, shall be considered to have a design pressure equal to the maximum allowable working pressure thus determined, except as limited by the rules of UCI-3, and shall be subjected to a hydrostatic test pressure in conformity with the rules of UCI-99.

MARKING AND REPORTS

UCI-115 GENERAL

The provisions for marking and reports in UG-115 through UG-120 shall apply without supplement to vessels constructed of cast iron.

PART UCL
REQUIREMENTS FOR WELDED PRESSURE VESSELS CONSTRUCTED OF MATERIAL WITH CORROSION RESISTANT INTEGRAL CLADDING, WELD METAL OVERLAY CLADDING, OR APPLIED LININGS

GENERAL

(25) UCL-1 SCOPE

The rules in Part UCL are applicable to pressure vessels or vessel parts that are constructed of base material with corrosion resistant integral or weld metal overlay cladding and to vessels and vessel parts that are fully or partially lined inside or outside with corrosion resistant plate, sheet, or strip, attached by welding to the base plates before or after forming or to the shell, heads, and other parts during or after assembly into the completed vessel.[13] These rules shall be used in conjunction with the general requirements in Subsection A and with the specific requirements in the applicable Parts of Subsections B and D.

UCL-2 METHODS OF FABRICATION

Vessels and vessel parts of base material with corrosion resistant integral or weld metal overlay cladding construction shall be fabricated by welding. Corrosion resistant linings may be attached by welding to vessels fabricated by any method of construction permitted under the rules of this section.

UCL-3 CONDITIONS OF SERVICE

Specific chemical compositions, heat treatment procedures, fabrication requirements, and supplementary tests may be required to assure that the vessel will be suitable for the intended service. This is particularly true for vessels subject to severe corrosive conditions, and also those vessels operating in a cyclic temperature service. These rules do not indicate the selection of an alloy suitable for the intended service or the amount of the corrosion allowance to be provided. See also informative and nonmandatory guidance regarding metallurgical phenomena in Section II, Part D, Nonmandatory Appendix A.

It is recommended that users assure themselves by appropriate tests, or otherwise, that the alloy material selected and its heat treatment during fabrication will be suitable for the intended service.

NOTE: Attention is called to the difficulties that have been experienced in welding materials differing greatly in chemical composition. Mixtures of uncertain chemical composition and physical properties are produced at the line of fusion. Some of these mixtures are brittle and may give rise to cracks during solidification or afterward. To avoid weld embrittlement, special care is required in the selection of lining material and welding electrodes, and in the application of controls over the welding process and other fabrication procedures.

MATERIALS

UCL-10 GENERAL

The base materials used in the construction of clad vessels and of those having applied corrosion linings shall comply with the requirements for materials given in UCS-5, UF-5, UHT-5, or ULW-5.

UCL-11 INTEGRAL AND WELD METAL OVERLAY CLAD MATERIAL

(a) Clad material used in constructions in which the design calculations are based on the total thickness including cladding [see UCL-23(c)] shall conform to one of the following specifications:

(1) SA-263, Stainless Chromium Steel-Clad Plate

(2) SA-264, Stainless Chromium–Nickel Steel-Clad Plate

(3) SA-265, Nickel and Nickel-Base Alloy-Clad Steel Plate

In addition to the above, weld metal overlay cladding may be used as defined in this Part.

(b) Base material with corrosion resistant integral or weld metal overlay cladding used in constructions in which the design calculations are based on the base material thickness, exclusive of the thickness of the cladding material, may consist of any base material satisfying the requirements of UCL-10 and any metallic corrosion resistant integral or weld metal overlay cladding material of weldable quality that in the judgment of the user is suitable for the intended service.

(c) Base material with corrosion resistant integral cladding in which any part of the cladding is included in the design calculations, as permitted in UCL-23(c), shall show a minimum shear strength of 20,000 psi (140 MPa) when tested in the manner described in the clad plate

specification. One shear test shall be made on each such clad plate as rolled, and the results shall be reported on the material test report.

When the composite thickness of the clad material is $^3/_4$ in. (19 mm) or less, and/or when the cladding metal thickness is nominally 0.075 in. (1.9 mm) or less, the “Bond Strength” test, as described in SA-263, SA-264, or SA-265, may be used in lieu of the bond “Shear Strength” test to fulfill the criteria for acceptable minimum shear strength, except that the bend test specimen shall be $1^1/_2$ in. (38 mm) wide by not more than $^3/_4$ in. (19 mm) in thickness and shall be bent, at room temperature, through an angle of 180 deg to the bend diameter provided for in the material specifications applicable to the backing metal. The results of the “Bond Strength” test shall be reported on the material test report.

(d) A shear or bond strength test is not required for weld metal overlay cladding.

(e) When any part of the cladding thickness is specified as an allowance for corrosion, such added thickness shall be removed before mill tension tests are made. When corrosion of the cladding is not expected, no part of the cladding need be removed before testing, even though excess thickness seems to have been provided or is available as corrosion allowance.

(f) Base material with corrosion-resistant integral cladding in which any part of the cladding is included in the design calculations, as permitted in UCL-23(c), that is constructed of multiple cladding plates welded together prior to being bonded to the base material shall have the cladding-alloy-to-cladding-alloy welding that is performed prior to bonding to the base material

(1) performed by a Manufacturer holding a Certificate of Authorization.

(2) radiographically examined for its full length in the manner prescribed in UW-51. In place of radiographic examination, welds may be ultrasonically examined for their full length (see UW-53).

(3) be supplied with a Partial Data Report if that welding is not performed by the vessel Manufacturer.

UCL-12 LINING

Material used for applied corrosion resistant lining may be any metallic material of weldable quality that in the judgment of the user is suitable for the intended purpose.

DESIGN

(25) UCL-20 GENERAL

(a) The rules in the following paragraphs apply specifically to pressure vessels and vessel parts constructed of base material with corrosion resistant integral or weld metal overlay cladding and those having applied corrosion resistant linings and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsections B and D.

(b) Minimum Thickness of Shells and Heads. The minimum thickness specified in UG-16.2 and UG-16.3 shall be the total thickness for clad material with corrosion resistant integral or weld metal overlay cladding and the base-material thickness for applied-lining construction.

UCL-23 MAXIMUM ALLOWABLE STRESS VALUES (25)

(a) Applied Corrosion Resistant Linings. The thickness of material used for applied lining shall not be included in the computation for the required thickness of any lined vessel. The maximum allowable stress value shall be that given for the base material in Table UCS-23, or UNF-23.

(b) Integrally Clad Material Without Credit for Full Cladding Thickness. Except as permitted in (c) below, design calculations shall be based on the total thickness of the clad material less the specified nominal minimum thickness of cladding. A reasonable excess thickness either of the actual cladding or of the same thickness of corrosion resistant weld metal may be included in the design calculations as an equal thickness of base material. The maximum allowable stress value shall be that given for the base material referenced in Table UCS-23, UF-6, or UHT-23 and listed in Section II, Part D, Subpart 1, Table 1A.

(c) Base Material with Corrosion Resistant Integral or Weld Metal Overlay Cladding With Credit for Cladding Thickness. When the base material with corrosion resistant integral cladding conforms to one of the specifications listed in UCL-11(a), or consists of an acceptable base material with corrosion resistant weld metal overlay and the joints are completed by depositing corrosion resisting weld metal over the weld in the base material to restore the cladding, the design calculations may be based on a thickness equal to the nominal thickness of the base material plus S_c/S_b times the nominal thickness of the cladding after any allowance provided for corrosion has been deducted, where

S_b = maximum allowable stress value for the base material at the design temperature

S_c = maximum allowable stress value for the integral cladding at the design temperature, or for corrosion resistant weld metal overlay cladding, that of the wrought material whose chemistry most closely approximates that of the cladding, at the design temperature

Where S_c is greater than S_b, the multiplier S_c/S_b shall be taken equal to unity. The maximum allowable stress value shall be that given for the base material referenced in Table UCS-23, UF-6, or UHT-23 and listed in Section II, Part D, Subpart 1, Table 1A. Vessels in which the cladding is included in the computation of required thickness shall not be constructed for internal pressure under the provisions of Table UW-12, column (c).

The thickness of the corrosion resistant weld metal overlay cladding deposited by manual processes shall be verified by electrical or mechanical means. One examination shall be made for every head, shell course, or any other pressure-retaining component for each welding process used. The location of examinations shall be chosen by the Inspector except that, when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the fabricator may select the locations.

UCL-24 MAXIMUM ALLOWABLE WORKING TEMPERATURE

(a) When the design calculations are based on the thickness of base material exclusive of lining or cladding thickness, the maximum service metal temperature of the vessel shall be that allowed for the base material.

(b) When the design calculations are based on the full thickness of base material with corrosion resistant integral or weld metal overlay cladding as permitted in UCL-23(c), the maximum service metal temperature shall be the lower of the values allowed for the base material referenced in Table UCS-23, UF-6, or UHT-23 and listed in Section II, Part D, Subpart 1, Table 1A, or refer to UCL-23(c) for corrosion resistant weld metal overlay cladding and the cladding material referenced in Table UHA-23 or Tables UNF-23.1 through UNF-23.5.

(c) The use of corrosion resistant integral or weld metal overlay cladding or lining material of chromium-alloy stainless steel with a chromium content of over 14% is not recommended for service metal temperatures above 800°F (425°C).

UCL-25 CORROSION OF CLADDING OR LINING MATERIAL

(a) When corrosion or erosion of the cladding or lining material is expected, the cladding or lining thickness shall be increased by an amount that in the judgment of the user will provide the desired service life.

(b) Telltale Holes. The requirements of UG-25(e) and UG-46(b) shall apply when telltale holes are used in clad or lined vessels, except that such holes may extend to the cladding or lining.

(25) ## UCL-26 THICKNESS OF SHELLS AND HEADS UNDER EXTERNAL PRESSURE

The thickness of shells or heads under external pressure shall satisfy the requirements of the Part of Subsection C or Subsection D applicable to the base material. The cladding may be included in the design calculations for clad material to the extent provided in UCL-23(b) and UCL-23(c).

UCL-27 LOW TEMPERATURE OPERATIONS

(a) The base materials used in the construction of vessels shall satisfy the requirements of UCS-66, UCS-67, UCS-68, Part UF, or UHT-5.

(b) When an applied corrosion-resistant lining is used in accordance with UCL-23(a), the impact test exemption temperature of the component shall apply to the base material only.

(c) When a corrosion-resistant integral cladding is used in accordance with UCL-23(b) or UCL-23(c), the impact test exemption temperature of the component shall be the warmer of the two values determined for the base material and the integral cladding material. The impact test exemption temperature for the integral cladding material shall be determined in accordance with Part UHA or Part UNF, as applicable.

FABRICATION

UCL-30 GENERAL (25)

The rules in the following paragraphs apply specifically to pressure vessels and vessel parts constructed of base material with corrosion resistant integral or weld metal overlay cladding and those having applied corrosion resistant linings, and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsections B and D.

UCL-31 JOINTS IN INTEGRAL OR WELD METAL OVERLAY CLADDING AND APPLIED LININGS

(a) The types of joints and welding procedure used shall be such as to minimize the formation of brittle weld composition by the mixture of metals of corrosion resistant alloy and the base material.

(b) When a shell, head, or other pressure part is welded to form a corner joint, as in Figure UW-13.2, the weld shall be made between the base materials either by removing the clad material prior to welding the joint or by using weld procedures that will assure the base materials are fused. The corrosion resistance of the joint may be provided by using corrosion resistant and compatible weld filler material or may be restored by any other appropriate means.

NOTE: Because of the different thermal coefficients of expansion of dissimilar metals, caution should be exercised in design and construction under the provisions of these paragraphs in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts such as may occur at points of stress concentration.

UCL-32 WELD METAL COMPOSITION

Welds that are exposed to the corrosive action of the contents of the vessel should have a resistance to corrosion that is not substantially less than that of the corrosion resistant integral or weld metal overlay cladding or lining. The use of filler metal that will deposit weld metal with practically the same composition as the material joined is recommended. Weld metal of different composition may be used provided it has better mechanical properties in the opinion of the manufacturer, and the user is satisfied that its resistance to corrosion is satisfactory for the intended service. The columbium content of columbium-stabilized austenitic stainless steel weld metal shall not exceed 1.00%, except when a higher columbium content is permitted in the material being welded.

UCL-33 INSERTED STRIPS IN CLAD MATERIAL

The thickness of inserted strips used to restore cladding at joints shall be equal to that of the nominal minimum thickness of cladding specified for the material backed, if necessary, with corrosion resistant weld metal deposited in the groove to bring the insert flush with the surface of the adjacent cladding.

UCL-34 POSTWELD HEAT TREATMENT

CAUTION: Postweld heat treatment may be in the carbide-precipitation range for unstabilized austenitic chromium–nickel steels, as well as within the range where a sigma phase may form, and if used indiscriminately could result in material of inferior physical properties and inferior corrosion resistance, which ultimately could result in failure of the vessel.

(a) Vessels or parts of vessels constructed of base material with corrosion resistant integral or weld metal overlay cladding or applied corrosion resistant lining material shall be postweld heat treated when the base material is required to be postweld heat treated.

When the thickness of the base material requires postweld heat treatment, it shall be performed after the application of corrosion resistant weld metal overlay cladding or applied corrosion resistant lining unless exempted by the Notes of Tables UCS-56-1 through UCS-56-11.

(b) Vessels or parts of vessels constructed of chromium stainless steel integral or weld metal overlay cladding and those lined with chromium stainless steel applied linings shall be postweld heat treated in all thicknesses, except vessels that are integrally clad or lined with Type 405 or Type 410S and welded with an austenitic electrode or non-air-hardening nickel–chromium–iron electrode need not be postweld heat treated unless required by (a) above.

UCL-35 RADIOGRAPHIC EXAMINATION

(a) General. Vessels or parts of vessels constructed of base material with corrosion resistant integral or weld metal overlay cladding and those having applied corrosion resistant linings shall be radiographed when required by the rules in UW-11, UCS-57, UHT-57, and UCL-36. The material thickness specified under these rules shall be the total material thickness for clad construction and the base material thickness for applied-lining construction, except as provided in (c) below.

(b) Base Material Weld Protected by a Strip Covering. When the base material weld in clad or lined construction is protected by a covering strip or sheet of corrosion resistant material applied over the weld in the base material to complete the cladding or lining, any radiographic examination required by the rules of UW-11, UHT-57, and UCS-57 may be made on the completed weld in the base material before the covering is attached.

(c) Base Material Weld Protected by an Alloy Weld. The radiographic examination required by the rules in UW-11, UHT-57, and UCS-57 shall be made after the joint, including the corrosion resistant layer, is complete, except that the radiographic examination may be made on the weld in the base material before the alloy cover weld is deposited, provided the following requirements are met.

(1) The thickness of the base material at the welded joint is not less than required by the design calculation.

(2) The corrosion resistant alloy weld deposit is non-air-hardening.

(3) The completed alloy weld deposit is spot examined by any method that will detect cracks.

(4) The thickness of the base material shall be used in determining the radiography requirement in (a) above.

UCL-36 EXAMINATION OF CHROMIUM STAINLESS STEEL CLADDING OR LINING

The alloy weld joints between the edges of adjacent chromium stainless steel cladding layers or liner sheets shall be examined for cracks as follows.

(a) Joints welded with straight chromium stainless steel filler metal shall be examined throughout their full length. The examination shall be by radiographic methods when the chromium stainless steel welds are in continuous contact with the welds in the base metal. Liner welds that are attached to the base metal, but merely cross the seams in the base metal, may be examined by any method that will disclose surface cracks.

(b) Joints welded with austenitic chromium–nickel steel filler metal or non-air-hardening nickel–chromium–iron filler metal shall be given a radiographic spot examination in accordance with UW-52. For lined construction, at least one spot examination shall include a portion of the liner weld that contacts weld metal in the base material.

UCL-40 WELDING PROCEDURES

Welding procedures for corrosion resistant weld overlay, composite (clad) metals, and attachment of applied linings shall be prepared and qualified in accordance with the requirements of Section IX.

UCL-42 ALLOY WELDS IN BASE METAL

Groove joints in base material and parts may be made with corrosion resistant alloy-steel filler metal, or groove joints may be made between corrosion resistant alloy steel and carbon or low alloy steel, provided the welding procedure and the welders have been qualified in accordance with the requirements of Section IX for the combination of materials used. Some applications of this rule are base metal welded with alloy-steel electrodes, and alloy nozzles welded to steel shells.

UCL-46 FILLET WELDS

Fillet welds of corrosion resistant metal deposited in contact with two materials of dissimilar composition may be used for shell joints under the limitations of UW-12, for connection attachments under the limitations of UW-15 and UW-16, and for any other uses permitted by this Division. The qualification of the welding procedures and welders to be used on fillet welds for a given combination of materials and alloy weld metal shall be made in accordance with the rules prescribed in Section IX.

INSPECTION AND TESTS

(25) ## UCL-50 GENERAL

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts constructed of base material with corrosion resistant integral or weld metal overlay cladding and those having applied corrosion resistant linings, and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsections B and D.

UCL-51 TIGHTNESS OF APPLIED LINING

A test for tightness of the applied lining that will be appropriate for the intended service is recommended, but the details of the test shall be a matter for agreement between the user and the manufacturer. The test should be such as to assure freedom from damage to the load carrying base material. When rapid corrosion of the base material is to be expected from contact with the contents of the vessel, particular care should be taken in devising and executing the tightness test.

Following the hydrostatic pressure test, the interior of the vessel shall be inspected to determine if there is any seepage of the test fluid through the lining. Seepage of the test fluid behind the applied lining may cause serious damage to the liner when the vessel is put in service. When seepage occurs, Nonmandatory Appendix F, F-4 shall be considered and the lining shall be repaired by welding. Repetition of the radiography, and heat treatment, or the hydrostatic test of the vessel after lining repairs is not required except when there is reason to suspect that the repair welds may have defects that penetrate into the base material, in which case the Inspector shall decide which one or more shall be repeated.

UCL-52 HYDROSTATIC TEST (25)

(a) The requirements for standard hydrostatic test in UG-99 shall apply to pressure vessels fabricated in accordance with the rules of Part UCL.

(b) The requirements of UG-99(l) are not applicable for pressure vessels and vessel parts constructed of base material with corrosion-resistant integral or weld metal overlay cladding.

MARKING AND REPORTS

UCL-55 GENERAL

The provisions for marking and reports in UG-115 through UG-120 shall apply to vessels that are constructed of base material with corrosion resistant integral or weld metal overlay cladding and those having applied corrosion resistant linings, with the following supplements to the Data Reports.

(a) Include specification and type of lining material.

(b) Include applicable paragraph in UCL-23 under which the shell and heads were designed.

PART UCD
REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF CAST DUCTILE IRON

GENERAL

UCD-1 SCOPE

The rules in Part UCD are applicable to pressure vessels and pressure vessel parts that are constructed of cast ductile iron,[60] and shall be used in conjunction with the general requirements in Subsection A insofar as these requirements are applicable to cast material.

UCD-2 SERVICE RESTRICTIONS

Cast ductile iron pressure vessels shall not be used for services as follows:

(a) to contain lethal[58] substances, either liquid or gaseous

(b) for unfired steam boilers [see U-1(g)(1)]

(c) for direct firing [see UW-2(d)]

(25) UCD-3 PRESSURE–TEMPERATURE LIMITATIONS

(a) The maximum design temperature shall not be higher than 650°F (345°C). The minimum design temperature shall not be less than −20°F (−29°C), and the design pressure shall not exceed 1,000 psi (7 MPa) unless the requirements in UG-24 for a casting quality factor of 90% are met, and the vessel contains liquids only.

(b) Cast ductile iron flanges and fittings covered by ASME B16.42 may be used in whole or as a part of a pressure vessel at the pressure–temperature ratings listed in that standard.

NOTE: Cast ductile iron flanges and fittings conforming in dimension to the Class 125 and 250 American National Standard for cast iron flanges and fittings may be used in whole or as a part of a pressure vessel at the pressure–temperature ratings listed in ASME B16.42, except that NPS $3\frac{1}{2}$ (DN 90) and smaller screwed and tapped flanges conforming in dimensions to the Class 125 ASME B16.1 for cast iron flanged fittings shall have identical ratings specified in ASME B16.1.

(c) Cast ductile iron flanges and fittings, Class 400 and higher, conforming in dimension to the carbon steel pipe flanges and flanged fittings in ASME B16.5 may be used in whole or as a part of a pressure vessel at the pressure–temperature ratings for carbon steel, material category 1.4, in that standard provided the temperature is not less than −20°F (−29°C) nor greater than 650°F (345°C) and provided that the pressure does not exceed 1,000 psi (7 MPa).

MATERIALS

UCD-5 GENERAL

All cast ductile iron material subject to stress due to pressure shall conform to the specifications given in Section II and shall be limited to those listed in Table UCD-23 except as otherwise provided in UG-11.

UCD-12 BOLT MATERIALS

The requirements for bolt materials, nuts, and washers shall be the same as for carbon and low alloy steels in UCS-10 and UCS-11.

DESIGN

UCD-16 GENERAL

The rules in the following paragraphs apply specifically to the design of pressure vessels and pressure vessel parts of cast ductile iron and shall be used in conjunction with the general requirements for *Design* in Subsection A insofar as these requirements are applicable to cast materials.

For components for which the Code provides no design rules, the provisions of UG-19(b) and UG-19(c) apply. If a proof test is performed, the rules of UCD-101 apply.

UCD-23 MAXIMUM ALLOWABLE STRESS VALUES

Table UCD-23 gives the maximum allowable stress values at the temperatures indicated for castings conforming to the Specification listed therein. These stress values shall be limited to the stress values in Table UCD-23 multiplied by the applicable casting quality factor given in UG-24.

UCD-28 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figures in Section II, Part D, Subpart 3 and the temperature limits of UG-20(c).

(25)

Table UCD-23
Maximum Allowable Stress Values in Tension for Cast Ductile Iron, ksi (MPa)

Spec. No.	Grade	Note	Specified Min. Tensile Strength [Note (1)]	For Metal Temp. Not Exceeding −20°F to 650°F (−29°C to 345°C)	Ext. Pressure Chart Figure No. [Note (2)]
SA-395	60-40-18	(1)	60 (414)	12.0 (82.7)	CD-1
	65-45-15	(1)	65 (450)	13.0 (89.6)	CD-1

GENERAL NOTES:
(a) To these stress values, a quality factor as specified in UG-24 shall be applied.
(b) In no case shall the longitudinal hub stress, S_H, for flange design be greater than the 1.5 times the maximum allowable stress in tension for cast ductile iron from Table UCD-23.

NOTES:
(1) The yield stresses in compression and tension for cast ductile iron are not sufficiently different to justify an increase in the allowable stress for bending.
(2) Refer to Section II, Part D, Subpart 3.

UCD-32 HEADS WITH PRESSURE ON CONCAVE SIDE

Heads with pressure on the concave side (plus heads) shall be designed in accordance with the equations in UG-32.

UCD-33 HEADS WITH PRESSURE ON CONVEX SIDE

The thickness of heads with pressure on the convex side (minus heads) shall not be less than the thickness required in UG-33.

UCD-35 SPHERICALLY SHAPED COVERS (HEADS)

(a) Circular cast ductile iron spherically shaped heads with bolting flanges, similar to Figure 1-6, sketches (b), (c), and (d) shall be designed in accordance with the provisions in 1-6, except that corners and fillets shall comply with the requirements of UCD-37.

(b) Circular cast ductile iron spherically shaped heads with bolting flanges other than those described in (a) above shall be designed in accordance with the following requirements.

(1) The head thickness shall be determined in accordance with the requirements in UG-32.

(2) The spherical and knuckle radii shall conform to the requirements in UG-32.

(3) Flanges made of cast ductile iron in compliance with SA-395 and conforming in dimensions to American National Standard for carbon steel given in ASME B16.5 may be used at pressures not exceeding 80% of the pressures permitted in those standards at their listed temperatures provided the temperature is not less than −20°F (−29°C) nor greater than 650°F (345°C) and provided that the adjusted service pressure does not exceed 1,000 psi (7 MPa).

NOTE: Cast ductile iron flanges conforming in dimension to the 125 lb and 250 lb American National Standard for cast iron flanges may be used for pressures not exceeding 80% of the American National Standard pressure ratings for 150 lb and 300 lb carbon steel flanges, respectively, at their listed temperatures provided the temperature is not less than −20°F (−29°C) nor greater than 650°F (345°C), except as in Note to UCD-3(b).

UCD-36 OPENINGS AND REINFORCEMENTS

(a) The dimensional requirements in UG-36 through UG-46 are applicable to cast ductile iron and shall be used in the design of openings and reinforcements in pressure vessels and pressure vessel parts which are cast integrally with the vessel or vessel part. In no case shall the thickness of the reinforcement, including the nominal thickness of the vessel wall, exceed twice the nominal thickness of the vessel wall.

(b) Cast ductile iron flanges, nozzles, and openings shall not be attached to steel or nonferrous pressure vessels or pressure parts by welding or brazing, nor shall they be considered to contribute strength to the vessel or part.

UCD-37 CORNERS AND FILLETS

A liberal radius shall be provided at projecting edges and in reentrant corners in accordance with good foundry practice. Abrupt changes in surface contour and in wall thickness at junctures shall be avoided. Fillets shall conform to the following:

(a) Fillets forming the transition between the pressure-containing walls and integral attachments, such as brackets, lugs, supports, nozzles, flanges, and bosses, shall have a radius not less than one-half the thickness of the pressure-containing wall adjacent to the attachment.

FABRICATION

UCD-75 GENERAL

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and pressure vessel parts of cast ductile iron and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A insofar as these requirements are applicable to cast materials.

UCD-78 REPAIRS IN CAST DUCTILE IRON MATERIAL (25)

(a) Imperfections which permit leakage in cast ductile iron materials may be repaired by using threaded plugs provided:

(1) the vessel or vessel parts operate within the temperature limits of UCD-3(a), and the design pressure does not exceed 1,000 psi (7 MPa);

(2) no welding is performed;

(3) the diameter of the plug shall not exceed the diameter of a standard NPS 2 (DN 50) pipe plug;

(4) the plugs, where practical, shall conform in all dimensions to standard NPS (DN) pipe plugs, and in addition they shall have full thread engagement corresponding to the thickness of the repaired section. (See Table UCD-78.1.) Where a tapered plug is impractical because of excess wall thickness in terms of plug diameter and coincident thread engagement, other types of plugs may be used, provided both full-thread engagement and effective sealing against pressure are obtained. Where possible, the ends of the plug should be ground smooth after installation to conform to the inside and outside contours of the walls of the pressure vessel or pressure part;

(5) the material from which the plug is manufactured shall conform in all respects to the material specification which applies to the pressure vessel or pressure vessel part;

(6) the machined surface of the drilled or bored hole before tapping shall be free from visible defects and the adjacent metal shown to be sound by radiographic examination;

(7) the thickness of any repaired section in relation to the size of plug used shall not be less than that given in Table UCD-78.1;

(8) the minimum radius of curvature of repaired sections of cylinders or cones in relation to the size of plug used shall not be less than that given in Table UCD-78.2;

(9) the ligament efficiency between any two adjacent plugs shall not be less than 80% where

$$E = \frac{p - \left(\frac{d_1 + d_2}{2}\right)}{p}$$

where

d_1, d_2 = respective diameters of the two plugs under consideration
E = ligament efficiency
p = distance between plug centers

(25) **Table UCD-78.1**

NPS (DN) Plug or Equivalent	Minimum Thickness of Repaired Section, in. (mm)
$\frac{1}{8}$ (6)	$\frac{11}{32}$ (9)
$\frac{1}{4}$ (8)	$\frac{7}{16}$ (11)
$\frac{3}{8}$ (10)	$\frac{1}{2}$ (13)
$\frac{1}{2}$ (15)	$\frac{21}{32}$ (17)
$\frac{3}{4}$ (20)	$\frac{3}{4}$ (19)
1 (25)	$\frac{13}{16}$ (21)
$1\frac{1}{4}$ (32)	$\frac{7}{8}$ (22)
$1\frac{1}{2}$ (40)	$\frac{15}{16}$ (24)
2 (50)	1 (25)

Table UCD-78.2 (25)

NPS (DN) Plug or Equivalent	Minimum Radius of Curvature of Cylinder or Cone, in. (mm)
$\frac{1}{8}$ (6)	$\frac{9}{16}$ (14)
$\frac{1}{4}$ (8)	$\frac{11}{16}$ (17)
$\frac{3}{8}$ (10)	$1\frac{1}{16}$ (27)
$\frac{1}{2}$ (15)	$1\frac{1}{4}$ (32)
$\frac{3}{4}$ (20)	2 (50)
1 (25)	$2\frac{1}{2}$ (64)
$1\frac{1}{4}$ (32)	4 (100)
$1\frac{1}{2}$ (40)	$5\frac{1}{4}$ (134)
2 (50)	$8\frac{1}{8}$ (207)

(10) the pressure vessel or pressure vessel part meets the standard hydrostatic test prescribed in UCD-99.

(b) Surface imperfections, such as undue roughness, which do not permit leakage in cast ductile iron materials may be repaired using driven plugs, provided:

(1) the vessel or vessel parts are to operate within the limits of UCD-3(a);

(2) no welding is performed;

(3) the material from which the plug is manufactured shall conform in all respects to the material specification which applies to the pressure vessel or pressure vessel part;

(4) the depth of the plug is not greater than 20% of the thickness of the section and its diameter is not greater than its engaged length;

(5) the pressure vessel or pressure vessel part meets the standard hydrostatic test prescribed in UCD-99.

INSPECTION AND TESTS

UCD-90 GENERAL

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and pressure vessel parts of cast ductile iron and shall be used in conjunction with the general requirements of *Inspection and Tests* in Subsection A insofar as these requirements are applicable to cast material.

UCD-99 STANDARD HYDROSTATIC TEST

(a) Cast ductile iron pressure vessels and pressure vessel parts shall be hydrostatically tested by the method prescribed in UG-99 except that the test pressure shall be two times the maximum allowable working pressure.

(b) Cast ductile iron pressure vessels and cast ductile iron pressure vessel parts shall not be painted or otherwise coated either internally or externally prior to the hydrostatic pressure test.

(c) In lieu of (b), a complete, mechanically assembled cast ductile iron pressure vessel, composed of parts, may be hydrostatically tested in the painted condition, provided all of the following requirements are met:

(1) each part has been documented by means of Nonmandatory Appendix W, Form U-2

(2) each part has been hydrostatically tested in accordance with (a)

(3) each part has been tested in the unpainted condition

(4) each part has been tested at a test pressure equal to or greater than that produced during the assembled hydrostatic test

(5) the test pressure of each part has accounted for static head produced by the assembled vessel

UCD-101 HYDROSTATIC TEST TO DESTRUCTION

(a) The maximum allowable working pressure of identical cast ductile iron vessels, based on testing one of them to destruction in accordance with UG-101(m), shall be

$$P_R = \left(\frac{P_B f}{5}\right)\left(\frac{\text{specified min. tensile strength}}{\text{avg. tensile strength of test specimens}}\right)$$

where

f = casting quality factor as defined in UG-24, which applies only to identical cast ductile iron vessels put into service

P_B = destruction test pressure

P_R = maximum allowable working pressure of identical cast ductile iron vessels

The principle of UG-101(c) shall be followed.

(b) The value of the average tensile strength of test specimens in the foregoing equation shall be determined from the test results of three test bars from the same ladle of iron as used in the part, or from three test specimens cut from the part.

(c) All pressure vessels or pressure vessel parts of the same material, design, and construction, whose maximum allowable working pressure is based on the destruction test of a sample vessel or part, shall be subjected to a hydrostatic test pressure of not less than twice the maximum allowable working pressure determined by the application of the rules in (a).

MARKING AND REPORTS

UCD-115 GENERAL

The provisions for marking and preparing reports in UG-115 through UG-120 shall apply without supplement to vessels constructed of cast ductile iron.

PART UHT
REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY HEAT TREATMENT

GENERAL

(25) UHT-1 SCOPE

The rules in Part UHT are applicable to pressure vessels and vessel parts that are constructed of ferritic steels suitable for welding, whose tensile properties have been enhanced by heat treatment, and shall be used in conjunction with the general requirements in Subsection A, with the specific requirements in Part UW of Subsection B, and with the applicable requirements in Subsection D. The heat treatment may be applied to the individual parts of a vessel prior to assembly by welding, to partially fabricated components, or to an entire vessel after completion of welding. This Part is not intended to apply to those steels approved for use under the rules of Part UCS but which are furnished in such thicknesses that heat treatment involving the use of accelerated cooling, including liquid quenching, is used to attain structures comparable to those attained by normalizing thinner sections. Integrally forged vessels, quenched and tempered, which do not contain welded seams, are not intended to be covered by the rules of this Part.

MATERIALS

UHT-5 GENERAL

(a) Steels covered by this Part subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table UHT-23.

The thickness limitations of the material specifications shall not be exceeded.

(b) Except when specifically prohibited by this Part [such as in UHT-18 and UHT-28], steels listed in Table UHT-23 may be used for the entire vessel or for individual components which are joined to other Grades listed in that Table or to other steels conforming to specifications listed in Part UCS or Part UHA.

(c) All steels listed in Table UHT-23 shall be tested for notch ductility, as required by UHT-6. These tests shall be conducted at a temperature not warmer than the minimum design metal temperature (see UG-20) but not warmer than +32°F (0°C). Materials may be used at temperatures colder than the minimum design metal temperature as limited in (1) and (2) below.

(1) When the coincident ratio defined in Figure UCS-66.1 (Figure UCS-66.1M) is 0.35 or less, the corresponding minimum design metal temperature shall not be colder than −155°F (−104°C).

(2) When the coincident ratio defined in Figure UCS-66.1 (Figure UCS-66.1M) is greater than 0.35, the corresponding minimum design metal temperature shall not be colder than the impact test temperature less the allowable temperature reduction permitted in Figure UCS-66.1 (Figure UCS-66.1M) and shall in no case be colder than −155°F (−104°C).

(d) All test specimens shall be prepared from the material in its final heat-treated condition or from full-thickness samples of the same heat similarly and simultaneously treated. Test samples shall be of such size that the prepared test specimens are free from any change in properties due to edge effects. When the material is clad or weld deposit overlayed by the producer or fabricator prior to quench and temper treatments, the full thickness samples shall be clad or weld deposit overlayed before such heat treatments.

(e) Where the vessel or vessel parts are to be hot formed or postweld heat treated (stress relieved), this identical heat treatment shall be applied to the test specimens required by the material specifications, including the cooling rate specified by the fabricator, which shall in no case be slower than that specified in the applicable material specification.

(f) All material shall be heat treated in accordance with the applicable material specifications.

UHT-6 TEST REQUIREMENTS

(a) See below.

(1) One Charpy V-notch test (three specimens) shall be made from each plate as heat treated, and from each heat of bars, pipe, tube, rolled sections, forged parts, or castings included in any one heat treatment lot.

(2) The test procedures, and size, location and orientation of the specimens shall be the same as required by UG-84 except that for plates the specimens shall be

oriented transverse to the final direction of rolling and for circular forgings the specimens shall be oriented tangential to the circumference.

(3) Each of the three specimens tested shall have a lateral expansion opposite the notch not less than the requirements shown in Figure UHT-6.1 (Figure UHT-6.1M).

(4) If the value of lateral expansion for one specimen is less than that required in Figure UHT-6.1 (Figure UHT-6.1M) but not less than $^{2}/_{3}$ of the required value, a retest of three additional specimens may be made, each of which must be equal to or greater than the required value in Figure UHT-6.1 (Figure UHT-6.1M). Such a retest shall be permitted only when the average value of the three specimens is equal to or greater than the required value in Figure UHT-6.1 (Figure UHT-6.1M). If the values required are not obtained in the retest or if the values in the initial test are less than the values required for retest, the material may be reheat treated. After reheat treatment, a set of three specimens shall be made, each of which must be equal to or greater than the required value in Figure UHT-6.1 (Figure UHT-6.1M).

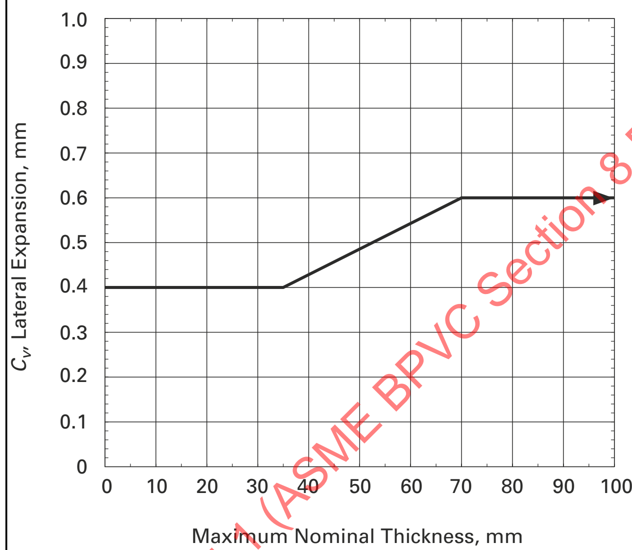
(b) Materials conforming to SA-353 and SA-553 for use at minimum design metal temperatures colder than −320°F (−196°C), materials conforming to SA-508, SA-517, SA-543, and SA-592 for use at minimum design metal temperatures colder than −20°F (−29°C), and materials conforming to SA-645, Grade A, for use at minimum design metal temperatures colder than −275°F (−171°C) shall have, in addition to the Charpy tests required under (a), drop-weight tests as defined by ASTM E208, made as follows:

(1) For plates $^{5}/_{8}$ in. (16 mm) thick and over, one drop-weight test (two specimens) shall be made for each plate as heat treated.

(2) For forgings and castings of all thicknesses, one drop-weight test (two specimens) shall be made for each heat in any one heat treatment lot. Specimen location for forgings shall be the same as that specified in SA-350, para. 7.2.3 for location of impact test specimens.

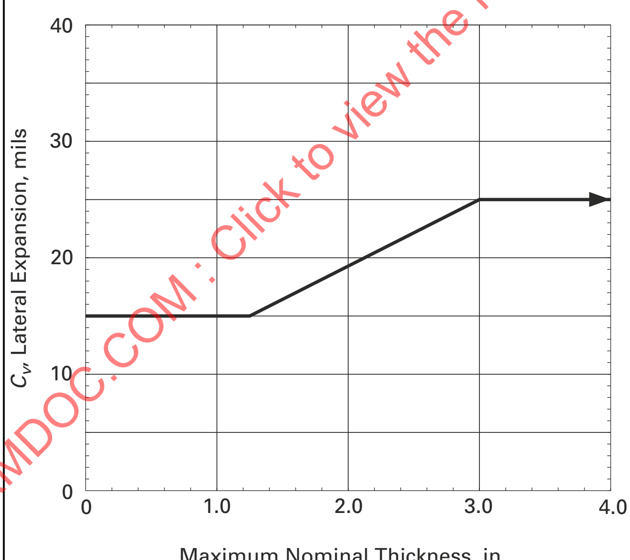
(3) Each of the two test specimens shall meet the "no-break" criterion, as defined by ASTM E208, at test temperature.

Figure UHT-6.1M
Charpy V-Notch Impact Test Requirements



GENERAL NOTE: For Table UCS-23 materials having a specified minimum tensile strength of 655 MPa or greater, and for Table UHT-23 materials.

Figure UHT-6.1
Charpy V-Notch Impact Test Requirements



GENERAL NOTE: For Table UCS-23 materials having a specified minimum tensile strength of 95,000 psi or greater, and for Table UHT-23 materials.

DESIGN

UHT-16 GENERAL (25)

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are constructed of heat-treated steels covered by this Part and shall be used in conjunction with the general requirements for *Design* in Subsection A; in Subsection B, Part UW; and in Subsection D.

UHT-17 WELDED JOINTS

(a) In vessels or vessel parts constructed of heat-treated steels covered by this Part except as permitted in (b) below, all Category A, B, and C joints, as defined in UW-3, and all other welded joints between parts of

the pressure-containing enclosure which are not defined by the category designation, shall be in accordance with Type No. (1) of Table UW-12. All joints of Category D shall be in accordance with Type No. (1) of Table UW-12 and Figure UHT-18.1 when the shell plate thickness is 2 in. (50 mm) or less. When the thickness exceeds 2 in. (50 mm), the weld detail may be as permitted for nozzles in Figures UHT-18.1 and UHT-18.2.

(b) For materials SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645, Grade A, the joints of various categories (see UW-3) shall be as follows:

(1) All joints of Category A shall be Type No. (1) of Table UW-12.

(2) All joints of Category B shall be Type No. (1) or (2) of Table UW-12.

(3) All joints of Category C shall be full penetration welds extending through the entire section at the joint.

(4) All joints of Category D attaching a nozzle neck to the vessel wall and to a reinforcing pad, if used, shall be full penetration groove welds.

(25) UHT-18 NOZZLES

(a) All openings regardless of size shall meet the requirements for reinforcing, nozzle geometry, and nozzle attachments and shall conform to details shown in Figure UHT-18.1 or as shown in Figure UHT-18.2 or sketch (y-l) or (z-l) in Figure UW-16.1 when permitted by the provisions of UHT-17(a), or as shown in Figure UW-16.1 when permitted by the provisions of UHT-17(b).

(b) Except for nozzles covered in (c) below, all nozzles and reinforcement pads shall be made of material with a specified minimum yield strength within ± 20% of that of the shell to which they are attached; however, pipe flanges, pipe, or communicating chambers may be of carbon, low, or high alloy steel welded to nozzle necks of the required material, provided:

(1) the joint is a circumferential butt weld located not less than $\sqrt{Rt_n}$ which, except for the nozzle type shown in Figure UHT-18.1, sketch (f), is measured from the limit of reinforcement as defined in UG-40. For Figure UHT-18.1, sketch (f), the $\sqrt{Rt_n}$ is measured as shown on that Figure. In these equations,

R = inside radius of the nozzle neck except for Figure UHT-18.1, sketch (f) where it is the inside radius of the vessel opening as shown in that Figure
t_n = nominal thickness of the nozzle

(2) the design of the nozzle neck at the joint is made on the basis of the allowable stress value of the weaker material;

(3) the slope of the nozzle neck does not exceed three to one for at least a distance of $1.5t_n$ from the center of the joint;

(4) the diameter of the nozzle neck does not exceed the limits given in Mandatory Appendix 1, 1-7 for openings designed to UG-36 through UG-44(a).

(c) Nozzles of nonhardenable austenitic-type stainless steel may be used in vessels constructed of steels conforming to SA-353; SA-553 Types I, II, and III; or SA-645, Grade A, provided the construction meets all of the following conditions:

(1) The nozzles are nonhardenable austenitic-type stainless steel conforming to one of the following specifications: SA-182, SA-213, SA-240, SA-312, SA-336, SA-403, SA-430, or SA-479.

(2) The maximum nozzle size is limited to NPS 4 (DN 100).

(3) None of the nozzles is located in a Category A or B joint.

(4) The nozzles are located so that the reinforcement area of one nozzle does not overlap the reinforcement area of an adjacent nozzle.

UHT-19 CONICAL SECTIONS

Conical sections shall be provided with a skirt having a length not less than $0.50\sqrt{rt}$ (where r is the inside radius of the adjacent cylinder and t is the thickness of the cone) or $1\frac{1}{2}$ in. (38 mm), whichever is larger. A knuckle shall be provided at both ends of the conical section; the knuckle radius shall not be less than 10% of the outside diameter of the skirt, but in no case less than three times the cone thickness.

UHT-20 JOINT ALIGNMENT

The requirements of UW-33 shall be met except that the following maximum permissible offset values shall be used in place of those given in UW-33(a):

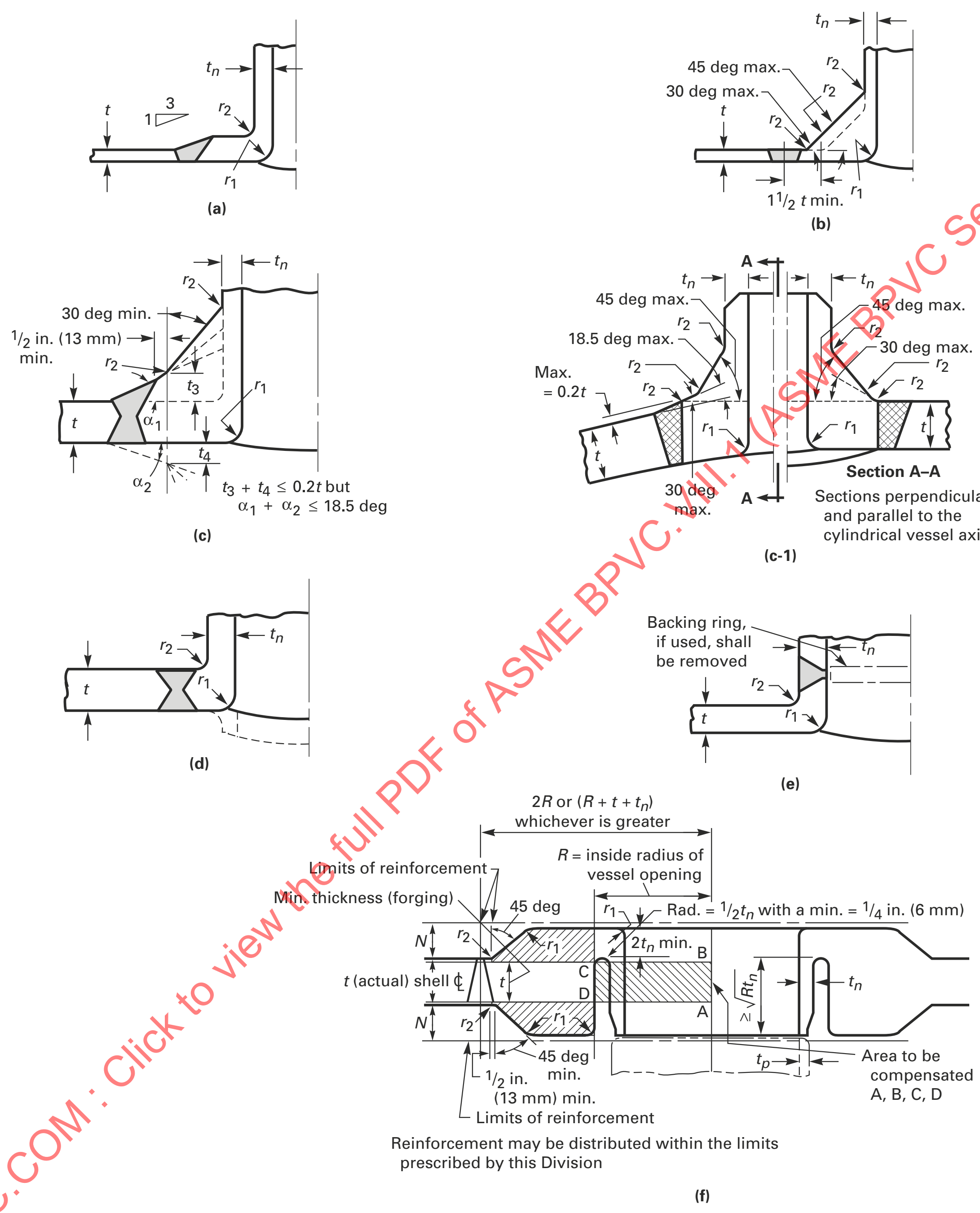
Section Thickness, in. (mm)	Joint Direction	
	Longitudinal	Circumferential
Up to $\frac{1}{2}$ (13), incl.	$0.2t$	$0.2t$
Over $\frac{1}{2}$ to $\frac{15}{16}$ (13 to 24), incl.	$\frac{3}{32}$ in. (2.5 mm)	$0.2t$
Over $\frac{15}{16}$ to $1\frac{1}{2}$ (24 to 38), incl.	$\frac{3}{32}$ in. (2.5 mm)	$\frac{3}{16}$ in. (5 mm)
Over $1\frac{1}{2}$ (38)	$\frac{3}{32}$ in. (2.5 mm)	Lesser of $\frac{1}{8}$ t or $\frac{1}{4}$ in. (6 mm)

UHT-23 MAXIMUM ALLOWABLE STRESS VALUES

(a) Section II, Part D, Subpart 1, Table 1A gives the maximum allowable stress values at the temperatures indicated for materials conforming to the specifications listed therein. Values may be interpolated for intermediate temperatures (see UG-23). For vessels designed to operate at a temperature colder than −20°F (−29°C), the allowable stress values to be used in design shall not exceed those given for temperatures of −20°F (−29°C) to 100°F (38°C).

(b) Shells of pressure vessels may be made from welded pipe or tubing listed in Table 1A.

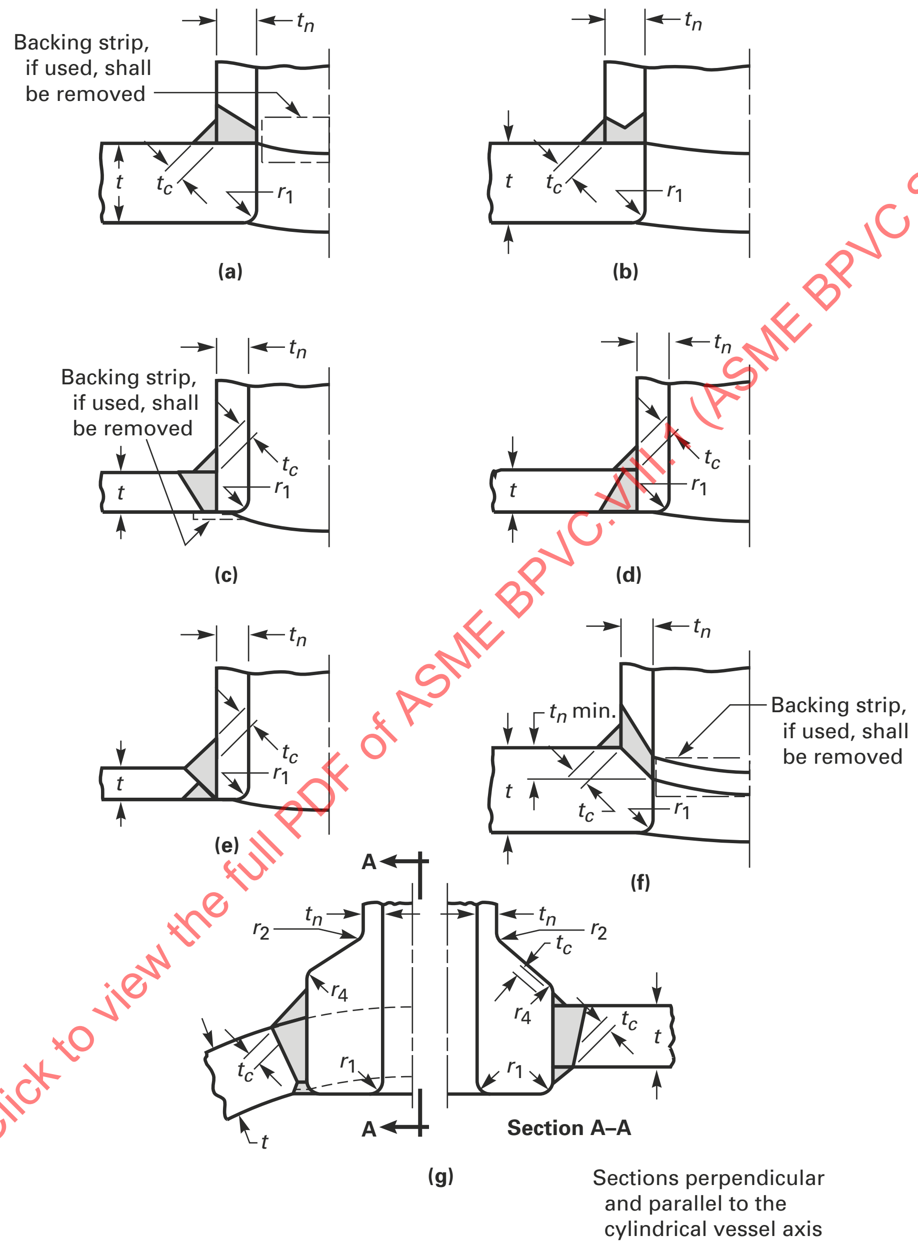
Figure UHT-18.1
Acceptable Welded Nozzle Attachment Readily Radiographed to Code Standards



Legend:

N	≤	$2^1/_2t_n$
r_1	=	$^1/_8t$ to $^1/_2t$
r_2	≥	$^3/_4$ in. (19 mm)
t	=	nominal thickness of shell or head
t_n	=	nominal thickness of nozzle
t_p	=	nominal thickness of attached pipe

Figure UHT-18.2
Acceptable Full Penetration Welded Nozzle Attachments Radiographable With Difficulty and Generally Requiring Special Techniques Including Multiple Exposures to Take Care of Thickness Variations



Legend:
r_1 = $^1/_8 t$ to $^1/_2 t$
r_2 ≥ $^3/_4$ in. (19 mm)
r_4 ≥ $^1/_4$ in. (6 mm)
t = nominal thickness of shell or head
t_c ≥ $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_n = nominal thickness of nozzle

Table UHT-23
Ferritic Steels With Properties Enhanced by Heat Treatment

Spec. No.	Type/Grade
SA-333	8
SA-334	8
SA-353	...
SA-420	WPL8
SA-487	4 Cl. B & E, CA6NM Cl. A
SA-508	4N Cl. 1 and 2
SA-517	A, B, E, F, J, P
SA-522	I
SA-533	B Cl. 3, D Cl. 3
SA-543	B, C
SA-553	I, II, and III
SA-592	A, E, F
SA-645	A
SA-724	A, B, C

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

UHT-25 CORROSION ALLOWANCE

Provision for possible deterioration due to the environment in which the vessel operates is the responsibility of the designer.

UHT-27 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figures in Section II, Part D, Subpart 3 and the temperature limits of UG-20(c).

UHT-28 STRUCTURAL ATTACHMENTS AND STIFFENING RINGS

(a) Except as permitted in (b) and (c) below, all structural attachments and stiffening rings which are welded directly to pressure parts shall be made of materials of specified minimum yield strength within ± 20% of that of the material to which they are attached.

(b) All permanent structural attachments welded directly to shells or heads constructed of materials conforming to SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645, Grade A, shall be of the material covered by these specifications or austenitic stainless steel of the type which cannot be hardened by heat treatment. If suitable austenitic stainless steel is used for permanent attachments, consideration should be given to the greater coefficient of expansion of the austenitic stainless steel.

(c) Minor attachments made from material that does not conform to a material specification permitted in this Division may be used and may be welded directly to the pressure part, provided the requirements shown below are satisfied. Minor attachments are defined as parts of small size, less than or equal to 0.375 in. (10 mm) thick or 5 in.^{3} (82 cm^3) in volume, that carry no load or an insignificant load such that a stress calculation in the designer's judgment is not required; examples include nameplates, insulation supports, and locating lugs.

(1) The minimum specified tensile strength of quenched and tempered steels for pressure parts shall be less than or equal to 100 ksi (690 MPa).

(2) The material shall be identified and suitable for welding in accordance with UW-5(b).

(3) The material shall be compatible insofar as welding is concerned with that to which the attachment is to be made.

(4) The specified minimum yield strength of minor attachments shall be within +20% and −60% of that of the material to which they are attached.

(5) If the minor attachment is welded in the area less than $2.5\sqrt{R_m t}$ from any gross structural discontinuity, where R_m is the mean radius of the shell, and t is the thickness of the shell, the stress evaluation in accordance with Section VIII, Division 2, Part 5 shall be performed.

(6) The effect of differential thermal expansion shall be considered when the thermal expansion coefficient of the minor attachment differs from that of the pressure part to which it is attached.

(7) Welding materials with the equivalent room-temperature tensile strength as that of quenched and tempered steels shall be used.

(8) If the continuous fillet weld is used, the leg dimension of fillet weld shall not be less than 0.25t, where t is the thickness of the minor attachment.

(9) The welds shall be postweld heat treated when required by UHT-56.

UHT-29 STIFFENING RINGS FOR SHELLS UNDER EXTERNAL PRESSURE

Rules covering the design of stiffening rings are given in UG-29. The design shall be based on the appropriate figure in Section II, Part D, Subpart 3 for the material used in the ring.

UHT-30 ATTACHMENT OF STIFFENING RINGS TO SHELLS

Rules covering the attachment of stiffening rings are given in UG-30. Attachments shall be made using a welding procedure qualified to Section IX for vessels constructed to Part UHT.

UHT-32 FORMED HEADS, PRESSURE ON CONCAVE SIDE

Except as provided in UG-32(d), 1-4(c), and 1-4(d), formed heads shall be limited to ellipsoidal and/or hemispherical heads designed in accordance with UG-32(c) or UG-32(e).

UHT-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

Ellipsoidal, hemispherical, and conical heads having pressure on the convex side (minus heads) shall be designed by the rules of UG-33, using the applicable external pressure charts referenced in Section II, Part D, Subpart 1, Table 1A and given in Section II, Part D, Subpart 3.

UHT-34 HEMISPHERICAL HEADS

When hemispherical heads are used, the head-to-shell transition of Figure UW-13.1, sketch (i) or Figure UW-13.1, sketch (k) shall be used. When the weld is in or adjacent to the tapered section, it shall be finished in a manner that will maintain the required uniform slope for the full length of the tapered section.

UHT-40 MATERIALS HAVING DIFFERENT COEFFICIENTS OF EXPANSION

When welding materials with austenitic electrodes, the differences between the coefficients of expansion and the strengths of the base material and the weld metal should be carefully considered, particularly for applications involving cyclic stresses.

(25) UHT-56 POSTWELD HEAT TREATMENT

(a) Before applying the detailed requirements and exemptions in these paragraphs, satisfactory weld procedure qualifications of the procedures to be used shall be performed in accordance with all of the variables in Section IX including conditions of postweld heat treatment or lack of postweld heat treatment and including restrictions listed below. When determining the thickness requiring postweld treatment in Table UHT-56 for clad or weld deposit overlayed vessels or parts of vessels, the total thickness of the material, including the clad and weld deposit overlay, shall be employed.

(b) Vessels or vessel parts constructed of steels listed in Table UHT-23 shall be postweld heat treated when required in Table UHT-56, except that postweld heat treatment shall be required for all thicknesses when joining the materials with the inertia and continuous drive friction welding processes.

(c) Postweld heat treatment shall be performed in accordance with UCS-56 as modified by the requirements of Table UHT-56. In no case shall the PWHT temperature exceed the tempering temperature. PWHT and tempering may be accomplished concurrently. The maximum cooling rate established in UCS-56.5.2 need not apply. Where accelerated cooling from the tempering temperature is required by the material specification, the same minimum cooling rate shall apply to PWHT.

(d) All welding of connections and attachments shall be postweld heat treated whenever required by Table UHT-56 based on the greatest thickness of material at the point of attachment of the head or shell [see (b) and (c)].

(e) When material of SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645, Grade A are postweld heat treated, the complete vessel or vessel component being so heat treated shall be maintained within the permissible temperature range defined in Table UHT-56.

UHT-57 EXAMINATION

(a) Radiography. Radiographic examination for the complete length of weld in accordance with the requirements of UW-51 is required for all welded joints of Type No. (1) of Table UW-12. The required radiographic examination shall be made after any corrosion-resistant alloy cover weld has been deposited.

(b) Nozzle Attachment Welds. Nozzle attachment welds as provided for in UHT-18, Figures UHT-18.1 and UHT-18.2 shall be radiographically examined in accordance with the requirements of UW-51, except that Figure UHT-18.2 type nozzles having an inside diameter of 2 in. (50 mm) or less shall be examined by a magnetic particle or liquid penetrant method. For nozzle attachments illustrated as sketches (a), (b), and (f) of Figure UHT-18.2, the exposed cross section of the vessel wall at the opening shall be included in the examination.

(c) All corrosion resistant overlay weld deposits shall be examined by the liquid penetrant method.

(d) Magnetic Particle Method. All welds, including welds for attaching nonpressure parts to heat-treated steels covered by this Part, shall be examined by the magnetic particle method after the hydrostatic test, except that those surfaces not accessible after the hydrostatic test shall be examined by the magnetic particle method at the last feasible stage of vessel fabrication. A magnetization method shall be used that will avoid arc strikes. Cracks shall be repaired or removed.

(e) Liquid Penetrant Method. As an acceptable alternative to magnetic particle examination or when magnetic particle methods are not feasible because of the nonferromagnetic character of the weld deposits, a liquid penetrant method shall be used. For vessels constructed of SA-333 Grade 8; SA-334 Grade 8; SA-353; SA-522; SA-553 Types I, II, and III; and SA-645 materials, welds not examined radiographically shall be examined by the liquid penetrant method either before or after the hydrotest. Cracks are unacceptable and shall be repaired or removed. Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Any relevant linear indications greater than $^1/_{16}$ in. (1.5 mm) shall be repaired or removed.

Table UHT-56
Postweld Heat Treatment Requirements for Materials in Table UHT-23

Spec. No.	Grade or Type	P-No./ Gr. No.	Nominal Thickness Requiring PWHT, in. (mm)	Notes	PWHT Temp., °F (°C)	Holding Time hr/in. (25 mm)	Holding Time Minimum, hr
Plate Steels							
SA-353	9Ni	11A/1	Over 2 (50)	(3)	1,025–1,085 (550–585)	1	2
SA-517	Grade A	11B/1	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-517	Grade B	11B/4	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-517	Grade E	11B/2	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-517	Grade F	11B/3	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-517	Grade J	11B/6	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-517	Grade P	11B/8	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-533	Types B, D, Cl. 3	11A/4	Over 0.58 (15)	...	1,000–1,050 (540–565)	$\frac{1}{2}$	$\frac{1}{2}$
SA-543	Types B, C, Cl. 1	11A/5	...	(2)	1,000–1,050 (540–565)	1	1
SA-543	Types B, C, Cl. 2	11B/10	...	(2)	1,000–1,050 (540–565)	1	1
SA-543	Types B, C, Cl. 3	11A/5	...	(2)	1,000–1,050 (540–565)	1	1
SA-553	Types I, II, III	11A/1	Over 2 (50)	(3)	1,025–1,085 (550–585)	1	2
SA-645	Grade A	11A/2	Over 2 (50)	...	1,025–1,085 (550–585)	1	2
SA-724	Grade A, B	1/4	None	...	NA	NA	NA
SA-724	Grade C	1/4	Over 1$\frac{1}{2}$ (38)	...	1,050–1,150 (565–620)	1	$\frac{1}{2}$
Castings							
SA-487	Class 4B	11A/3	Over 0.58 (15)	...	1,000–1,050 (540–565)	1	$\frac{1}{4}$
SA-487	Class 4E	11A/3	Over 0.58 (15)	...	1,000–1,050 (540–565)	1	$\frac{1}{4}$
SA-487	Class CA 6NM	6/4	Over 0.58 (15)	...	1,050–1,150 (565–620)	1	$\frac{1}{4}$
Pipes and Tubes							
SA-333	Grade 8	11A/1	Over 2 (50)	...	1,025–1,085 (550–585)	1	2
SA-334	Grade 8	11A/1	Over 2 (50)	...	1,025–1,085 (550–585)	1	2
Forgings							
SA-508	Grade 4N Cl. 1	11A/5	...	(2)	1,000–1,050 (540–565)	1	1
SA-508	Grade 4N Cl. 2	11B/10	...	(2)	1,000–1,050 (540–565)	1	1
SA-522	Type I	11A/1	Over 2 (50)	...	1,025–1,085 (550–585)	1	2
SA-592	Grade A	11B/1	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-592	Grade E	11B/2	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$
SA-592	Grade F	11B/3	Over 0.58 (15)	(1)	1,000–1,100 (540–595)	1	$\frac{1}{4}$

GENERAL NOTE: NA = not applicable.

NOTES:
(1) See UHT-82(g).
(2) PWHT is neither required nor prohibited. Consideration should be given to the possibility of temper embrittlement. The cooling rate from PWHT, when used, shall not be slower than that obtained by cooling in still air.
(3) See UHT-82(k).

FABRICATION

(25) UHT-75 GENERAL

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of heat-treated steels covered by this Part and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and, when applicable, with the specific requirements for *Fabrication* in Subsection B, Part UW and in Subsection D.

UHT-79 FORMING PRESSURE PARTS

The selected thickness of material shall be such that the forming processes will not reduce the thickness of the material at any point below the minimum value required by the rules.

(a) Pieces that are formed after heat treatment at a temperature lower than the final tempering shall be heat treated in accordance with Table UHT-56 when the extreme fiber elongation from forming exceeds 5% as determined by the equations in Table UG-79-1.

(b) Pieces that are formed at temperatures equal to or higher than the original tempering shall be reheat treated in accordance with the applicable material specification, either before or after welding into the vessel.

UHT-80 HEAT TREATMENT

(a) Heating Furnace. Furnaces for heating, for quenching, for normalizing, and for tempering shall be provided with suitable equipment for the automatic recording of temperatures. The temperature of the vessel or vessel part during the holding period shall be recorded and shall be controlled within ±25°F (±15°C).

(b) Liquid quenching of flat plates and individual parts shall be done as required by the applicable material specifications.

(c) Formed plates for shell sections and heads may be quenched by sprays or immersion.

(d) Entire vessels, after completion of all welding operations, may be quenched by sprays or immersion.

(e) The design and operation of spray equipment and the size of tanks and provision for forced circulation shall be such as to produce a severity of quench in the quenched item sufficient to meet, in representative test specimens after tempering, the requirements of the materials specifications.

UHT-81 HEAT TREATMENT VERIFICATION TESTS

(a) Tests shall be made to verify that the heat treatments, and subsequent thermal treatments, performed by the fabricator have produced the required properties.

(b) One or more test coupons representative of the material and the welding in each vessel or vessel component shall be heat treated with the vessel or vessel component.

The requirements of (c) and (d) below are to be taken as minimum steps toward these objectives.

(c) See below.

(1) One or more test coupons from each lot of material in each vessel [see (d)] shall be quenched with the vessel or vessel component. A lot is defined as material from the same melt, quenched or normalized simultaneously and whose thicknesses are within plus or minus 20% or $^1/_2$ in. (13 mm) of nominal thickness, whichever is smaller. The test coupons shall be so proportionated that tensile and impact tests may be taken from the same locations relative to thickness as are required by the applicable material specifications. Weld metal tests shall be taken from the same locations relative to thickness as are required by the materials specifications for plates used in the component to be treated. The gage length of tensile specimens and the middle third of the length of impact specimens must be located at a minimum distance of $1 \times t$ from the quenched edge and/or end of the test coupon, where t is the thickness of the material which the test coupon represents. If desired, the effect of this distance may be achieved by temporary attachment of suitable thermal buffers. The effectiveness of such buffers shall be demonstrated by tests.

(2) In cases where the test coupon is not attached to the part being treated, it shall be quenched from the same heat treatment charge and under the same conditions as the part it represents. It shall be so proportioned that test specimens may be taken from the locations prescribed in (1) above.

(d) Tempering

(1) Attached Test Coupons. The coupons shall remain attached to the vessel or vessel component during tempering, except that any thermal buffers may be removed after quenching. After the tempering operation and after removal from the component, the coupon shall be subjected to the same thermal treatment(s), if any, to which the vessel or vessel component will be later subjected. The holding time at temperature shall not be less than that applied to the vessel or vessel component (except that the total time at each temperature may be applied in one heating cycle) and the cooling rate shall be no faster.

(2) Separate Test Coupons. Test coupons which are quenched separately as described in (c)(2) above shall be tempered similarly and simultaneously with the vessel or component they represent. The conditions for subjecting the test coupons to subsequent thermal treatment(s) shall be as described in (c)(1) above.

(e) Number of Tests. One tensile test and one impact test shall be made on material from coupons representing each lot of material in each vessel or vessel component heat treated. A lot is defined as material from the same melt quenched simultaneously and whose thicknesses are within plus or minus 20%, or $^1/_2$ in. (13 mm), of nominal thickness, whichever is smaller.

(1) Coupons not containing welds shall meet the complete tensile requirements of the material specification and impact requirements of this part.

(2) Coupons containing weld metal shall be tested across the weld and shall meet the ultimate tensile strength requirements of the material specifications; in addition, the minimum impact requirements shall be met by samples with notches in the weld metal. The form and dimension of the tensile test specimen shall conform to Section IX, Figure QW-462.1(d). Yield strength and elongation are not a requirement of this test. Charpy impact testing shall be in accordance with the requirements of UHT-6.

UHT-82 WELDING

(a) The qualification of the welding procedure and the welders shall conform to the requirements of Section IX, and such qualification tests shall be performed on postweld heat-treated specimens when a postweld heat treatment is used.

(b) Due consideration shall be given to electrodes and filler metals for all welding processes to minimize the sources for hydrogen. When low-alloy steel electrodes and filler metals are used for welding the materials listed in Table UHT-23, their classifications shall include a supplemental diffusible hydrogen designator as defined in each of the following specifications:

(1) SFA-5.5 for SMAW

(2) SFA-5.23 for SAW

(3) SFA-5.2.8 or SFA-5.36 for gas-shielded arc welding

(4) SFA-5.29 or SFA-5.36 for FCAW

Practices used for controlling the storage of electrodes, rods, and fluxes shall be developed by the vessel manufacturer or those recommended by the electrode manufacturer.

(c) Filler metal containing more than 0.06% vanadium shall not be used for weldments subject to postweld heat treatment.

(d) For welded vessels, the deposited weld metal and the heat-affected zone shall meet the impact test requirements of UG-84, except that the Charpy V-notch tests and requirements of UHT-6(a) shall apply.

(e) The following materials are exempt from production impact tests of the weld metal in accordance with UG-84 under the conditions given in (1) through (5) below:

Specification No.	UNS No.	P-No./Group No.
SA-353	K81340	11A/1
SA-522 Type I	K81340	11A/1
SA-553 Type I	K81340	11A/1
SA-553 Type II	K71340	11A/1
SA-553 Type III	K61365	11A/1
SA-645, Grade A	K41583	11A/2

(1) One of the following high nickel alloy filler metals is used:

Specification No.	Classification	F-No.
SFA-5.11	ENiCrMo-3	43
SFA-5.11	ENiCrMo-6	43
SFA-5.11	ENiCrFe-2	43
SFA-5.11	ENiCrFe-3	43
SFA-5.14	ERNiCr-3	43
SFA-5.14	ERNiCrFe-6	43
SFA-5.14	ERNiCrMo-3	43
SFA-5.14	ERNiCrMo-4	44

(2) All required impact tests shall be performed as part of the procedure qualification tests as specified in UG-84.

(3) Production impact tests of the heat-affected zone are performed in accordance with UG-84.8.

(4) The welding processes are limited to gas metal arc, shielded metal arc, and gas tungsten arc.

(5) The minimum allowable temperature of the vessel shall be not less than −320°F (−195°C).

(f) For materials SA-508 and SA-543, the following, in addition to the variables in Section IX, QW-250, shall be considered as essential variables requiring requalification of the welding procedure:

(1) a change in filler metal SFA classification or to weld metal not covered by an SFA specification.

(2) an increase in the maximum interpass temperature or a decrease in the minimum specified preheat temperature. The specified range between the preheat and interpass temperatures shall not exceed 150°F (85°C).

(3) a change in the heat treatment (Procedure qualification tests shall be subjected to heat treatment essentially equivalent to that encountered in fabrication of the vessel or vessel parts including the maximum total aggregate time at temperature or temperatures and cooling rates.)

(4) a change in the type of current (AC or DC), polarity, or a change in the specified range for amp, volt, or travel speed.

(5) a change in the thickness T of the welding procedure qualification test plate as follows:

(-a) for welded joints which are quenched and tempered after welding, any increase in thickness [the minimum thickness qualified in all cases is $\frac{1}{4}$ in. (6 mm)];

(-b) for welded joints which are not quenched and tempered after welding, any change as follows:

T less than $\frac{5}{8}$ in. (16 mm)	Any decrease in thickness (the maximum thickness qualified is $2T$)
$\frac{5}{8}$ in. (16 mm) and over	Any departure from the range of $\frac{5}{8}$ in. (16 mm) to $2T$

(6) for the shielded metal arc, submerged arc, and gas-shielded and flux-cored arc welding processes, an increase in the supplemental diffusible hydrogen designator from that used during procedure qualification.

(7) preheat shall be 100°F (38°C) minimum for material thickness up to and including $\frac{1}{2}$ in. (13 mm); 200°F (95°C) minimum for material above $\frac{1}{2}$ in. (13 mm) to and including $1\frac{1}{2}$ in. (38 mm); 300°F (150°C) minimum above $1\frac{1}{2}$ in. (38 mm). Preheat temperature shall be maintained for a minimum of 2 hr after completion of the weld joint.

(g) For SA-517 and SA-592 materials the requirements of (f)(1), (f)(2), (f)(3), (f)(4), and (f)(6), in addition to the variables in Section IX, QW-250, shall be considered as essential variables requiring requalification of the welding procedure.

(h) For base metals in Table UHT-23 other than those listed in (f) and (g), in addition to the variables in Section IX, QW-250, an increase in the diffusible hydrogen designator from that used during procedure qualification shall require requalification.

(i) Electrode classifications for SMAW of SA-487, SA-508, SA-517, SA-543, and SA-592 shall also bear the supplemental hydrogen content designator "R," indicating a flux coating moisture content not greater than 0.2%, by

weight in the as-received or reconditioned condition. Once opened, electrode storage and handling shall be controlled to minimize absorption of moisture from the ambient atmosphere. Practices used for controlling the moisture content shall be developed by the vessel manufacturer or those recommended by the electrode manufacturer.

(j) The PWHT as required by Table UHT-56 may be waived for SA-517 and SA-592 materials with a nominal thickness over 0.58 in. to 1$^1/_4$ in. (15 mm to 32 mm), inclusive, provided the following conditions are met:

(1) a minimum preheat of 200°F (95°C) and a maximum interpass of 400°F (205°C) is used;

(2) after completion of welding and without allowing the weldment to cool below the minimum preheat temperature, the temperature of the weldment is raised to a minimum of 400°F (205°C) and maintained at that temperature for at least 4 hr; and

(3) all welds are examined by nondestructive examination in accordance with the provisions of this Part.

(k) The PWHT as required by Table UHT-56 may be waived for SA-353 and SA-553, Type I materials with a thickness over 2 in. (50 mm), provided the following conditions are met:

(1) One of the high nickel alloy filler metals listed in UHT-82(e)(1) is used.

(2) The welding processes are limited to SMAW, SAW, GTAW, and GMAW.

(3) Impact tests are performed as part of the welding procedure qualification tests as specified in UG-84. Production impact tests are performed in accordance with UG-84(i). Lateral expansions in weld metals and heat-affected zones of each of the specimens shall be not less than 0.032 in. (0.8 mm) for both welding procedure qualification tests and production impact tests.

UHT-83 METHODS OF METAL REMOVAL

(a) Plate edges, welding bevels, chamfering and other operations involving the removal of metal shall be by machining, chipping, or grinding except as provided in (b) below.

(b) When metal removal is accomplished by methods involving melting, such as gas cutting or arc-air gouging, etc., it shall be done with due precautions to avoid cracking. Where the cut surfaces are not to be subsequently eliminated by fusion with weld deposits, they shall be removed by machining or grinding to a depth of at least $^1/_{16}$ in. (1.5 mm) followed by inspection by magnetic particle or liquid penetrant methods.

CAUTION: The properties of the base metal may be adversely affected by excessive local heat inputs.

UHT-84 WELD FINISH

The requirements of UW-35(a), UW-35(b), and UW-51(b) shall be met except that for SA-517 material the maximum weld reinforcement shall not exceed 10% of the plate thickness or $^1/_8$ in. (3.0 mm), whichever is less. The edge of the weld deposits shall merge smoothly into the base metal without undercuts or abrupt transitions; this requirement shall apply to fillet and groove welds as well as to butt welds.

UHT-85 STRUCTURAL AND TEMPORARY WELDS

(a) Welds for pads, lifting lugs and other nonpressure parts, as well as temporary lugs for alignment, shall be made by qualified welders in full compliance with a qualified welding procedure.

(b) Temporary welds shall be removed and the metal surface shall be restored to a smooth contour. The area shall be inspected by magnetic particle or liquid penetrant method for the detection and elimination of cracks. If repair welding is required, it shall be in accordance with qualified procedures, and the finished weld surface shall be inspected as required in UHT-57(b) or UHT-57(c). Temporary welds and repair welds shall be considered the same as all other welds so far as requirements for qualified operators and procedures and for heat treatment are concerned.

UHT-86 MARKING ON PLATES AND OTHER MATERIALS (25)

Any steel stamping shall be done with "low stress" stamps as commercially available. Steel stamping of all types may be omitted on material below $^1/_2$ in. (13 mm) in thickness. For the use of other markings in lieu of stamping, see UG-77.1(b).

INSPECTION AND TESTS

UHT-90 GENERAL (25)

The provisions for inspection and testing in Subsections A, B, and D shall apply to vessels and vessel parts constructed of steels covered by this Part.

MARKING AND REPORTS

UHT-115 GENERAL

The provisions for marking and reports in UG-115 through UG-120 shall apply to pressure vessels or parts constructed in whole or in part of steels covered by this Part, except that the use of nameplates is mandatory for shell thicknesses below $^1/_2$ in. (13 mm). Nameplates are preferred on vessels constructed of steels covered by this Part in all thicknesses in preference to stamping. In addition to the required marking, the letters UHT shall be applied below the Certification Mark and U or PRT VIII-1 Designator.

PART ULW
REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY LAYERED CONSTRUCTION

INTRODUCTION

The rules in Section VIII, Divisions 1 and 2 to cover the construction of layered vessels have been developed to parallel each other as far as can be done within the parameters of each Division. The design criteria may influence the selection of the Division. There are several manufacturing techniques used to fabricate layered vessels, and these rules have been developed to cover most techniques used today for which there is extensive documented construction and operational data. Some acceptable layered shell types are shown in Figure ULW-2.1. Some acceptable layered head types are shown in Figure ULW-2.2.

(25) ULW-1 SCOPE

The rules in Part ULW are applicable to pressure vessels or parts thereof fabricated by layered construction as defined in Mandatory Appendix 3, 3-2 and ULW-2. These rules shall be used in conjunction with the requirements of Subsections A, B, C, and D, except for directly fired vessels described in UW-2(d) in Subsection B and except for Parts UCI and UCD in Subsection C, or except as otherwise required in this Part. The requirements for vessels that are to contain lethal substances, UW-2(a), apply only to the inner shell and the inner heads. Brazing of layered parts is not permitted except for the inner shell, inner head, and special solid wall fittings. The Manufacturer's Quality Control System as required by U-2(h) and Mandatory Appendix 10 shall include the construction procedure that will outline the sequence and method of application of layers and measurement of layer gaps.

ULW-2 NOMENCLATURE

The following terms are used in Part ULW relative to layered vessels:

(a) Layered Vessel. A vessel having a shell and/or heads made up of two or more separate layers.

(b) Inner Shell. The inner cylinder that forms the pressure tight membrane.

(c) Inner Head. The inner head that forms the pressure tight membrane.

(d) Shell Layer. Layers may be cylinders formed from plate, sheet, or forging, or the equivalent formed by coiling, or by helically wound interlocking strips. (This does not include wire winding.)

(e) Head Layer. Any one of the head layers of a layered vessel except the inner head.

(f) Overwraps. Layers added to the basic shell or head thickness for the purpose of building up the thickness of a layered vessel for reinforcing shell or head openings, or making a transition to thicker sections of the layered vessel.

(g) Dummy Layer. A layer used as a filler between the inner shell (or inner head) and other layers, and not considered as part of the required total thickness.

MATERIAL

ULW-5 GENERAL

Material used for pressure parts shall conform to one of the specifications permitted in the applicable Parts of Subsections A, B, and C, except for 5%, 8%, and 9% nickel steel materials which are permitted only for inner shells and inner heads.

DESIGN

ULW-16 GENERAL

(a) The design of layered pressure vessels shall conform to the design requirements given in UG-16 through UG-46 except that:

(1) reinforcement of openings is required as illustrated in Figure ULW-18.1;

(2) in calculating the requirements for vacuum per UG-28, only the inner shell or inner head thickness shall be used;

(3) layered shells under axial compression shall be calculated using UG-23, and utilizing the total shell thickness.

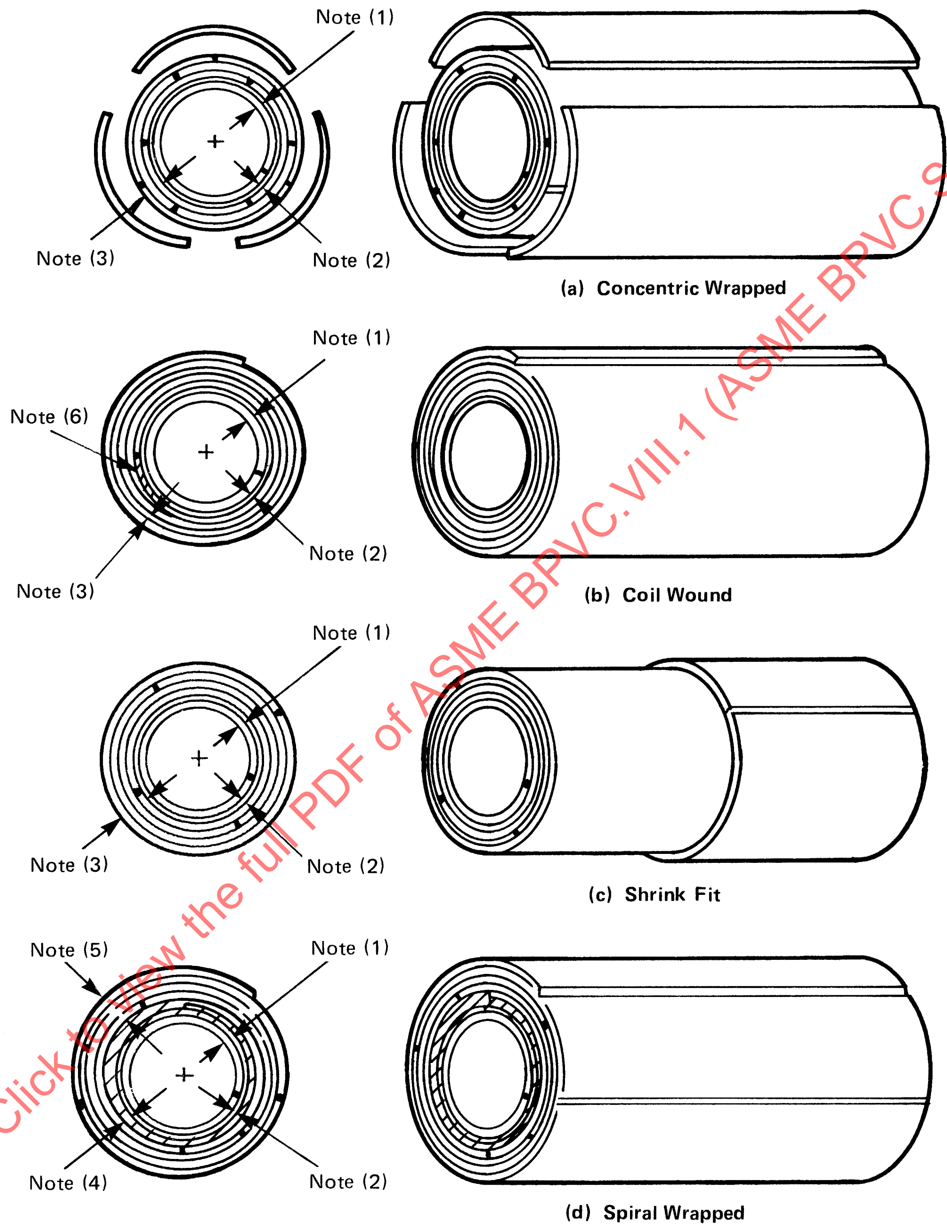
(b) The inner shell or inner head material which has a lower allowable design stress than the layer materials may only be included as credit for part of the total wall thickness if S_1 is not less than $0.50S_L$ by considering its effective thickness to be

$$t_{eff} = t_{act}\frac{S_1}{S_L}$$

where

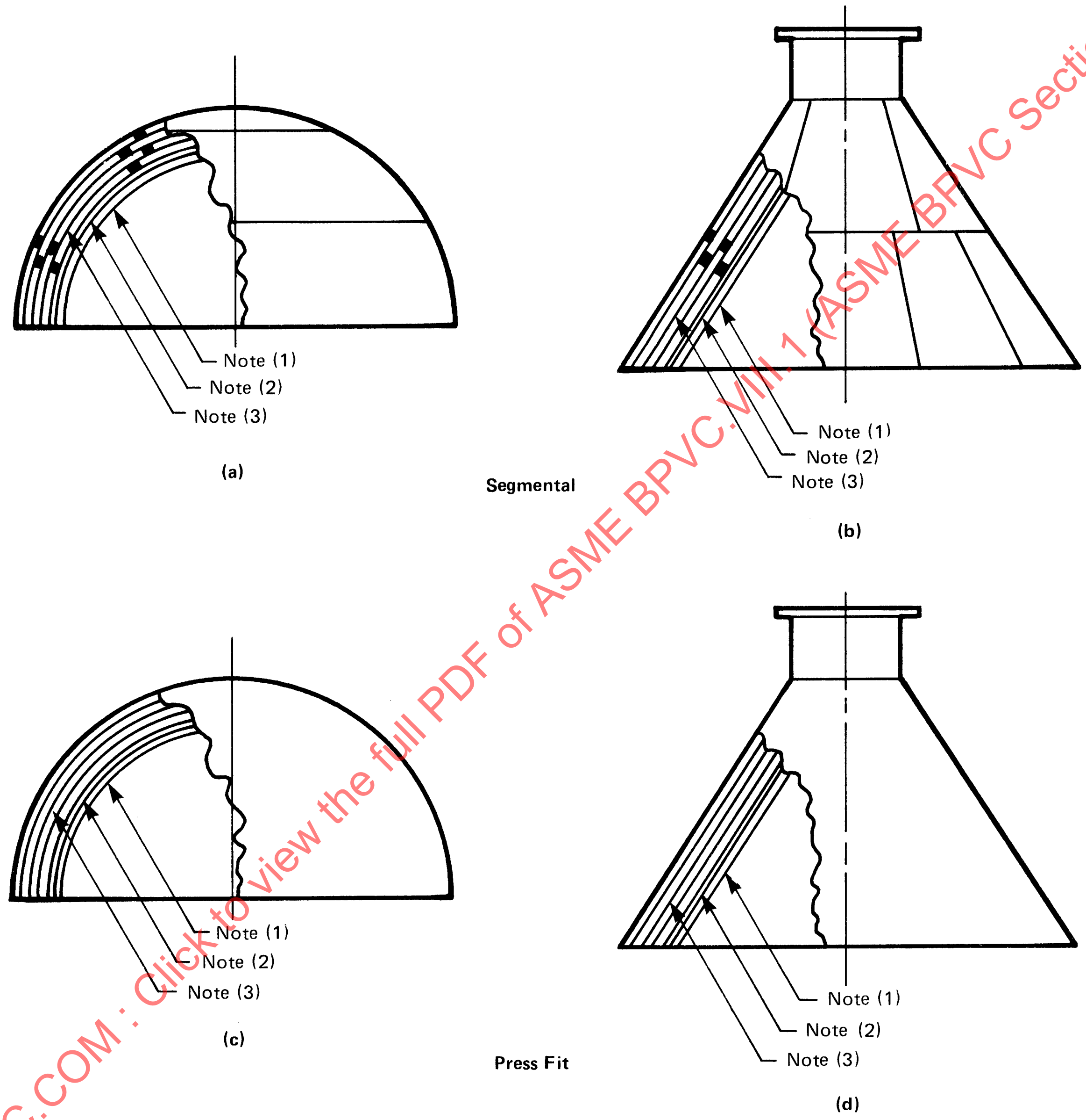
S_1 = design stress of inner shell or inner head

Figure ULW-2.1
Some Acceptable Layered Shell Types



NOTES:
(1) Inner shell
(2) Dummy layer (if used)
(3) Layers
(4) Shell layer (tapered)
(5) Balance of layers
(6) Gap

Figure ULW-2.2
Some Acceptable Layered Head Types



NOTES:
(1) Inner head
(2) Dummy layer (if used)
(3) Head layers

S_L = design stress of layers
t_{act} = nominal thickness of inner shell or inner head
t_{eff} = effective thickness of inner shell or inner head

(c) Layers in which the maximum allowable stress value of the materials is within 20% of the other layers may be used by prorating the maximum allowable stress of the layers in the thickness formula, provided the materials are compatible in modulus of elasticity and coefficient of thermal expansion.

(d) The minimum thickness of any layer shall not be less than $^1/_8$ in. (3 mm).

(e) Torispherical layered heads are not permitted.

ULW-17 DESIGN OF WELDED JOINTS

(a) Category A and B joints of inner shells and inner heads of layered sections shall be as follows:

(1) Category A joints shall be Type No. (1) of Table UW-12.

(2) Category B joints shall be Type No. (1) or (2) of Table UW-12.

(b) Category A joints of layered sections shall be as follows:

(1) Category A joints of layers over $^7/_8$ in. (22 mm). in thickness shall be Type No. (1) of Table UW-12.

(2) Category A joints of layers $^7/_8$ in. (22 mm) or less in thickness shall be of Type No. (1) or (2) of Table UW-12, except the final outside weld joint of spiral wrapped layered shells may be a single lap weld.

(c) Category B joints of layered shell sections to layered shell sections, or layered shell sections to solid shell sections, shall be of Type (1) or (2) of Table UW-12.

(1) Category B joints of layered sections to layered sections of unequal thickness shall have transitions as shown in Figure ULW-17.1, sketch (a) or (b).

(2) Category B joints of layered sections to solid sections of unequal thickness shall have transitions as shown in Figure ULW-17.1, sketch (c), (d), (e), or (f).

(3) Category B joints of layered sections to layered sections of equal thickness shall be as shown in Figure ULW-17.6, sketch (b), (c), (f), or (g).

(4) Category B joints of layered sections to solid sections of equal thickness shall be as shown in Figure ULW-17.6, sketch (a) or (e).

(d) Category A joints of solid hemispherical heads to layered shell sections shall be of Type (1) or (2) of Table UW-12.

(1) Transitions shall be as shown in Figure ULW-17.2, sketch (a), (b-1), (b-2), or (b-3) when the hemispherical head thickness is less than the thickness of the layered shell section and the transition is made in the layered shell section.

(2) Transitions shall be as shown in Figure ULW-17.2, sketch (c), (d-1), or (e) when the hemispherical head thickness is greater than the thickness of the layered shell section and transition is made in the layered shell section.

(3) Transition shall be as shown in Figure ULW-17.2, sketch (f) when the hemispherical head thickness is less than the thickness of the layered shell section and the transition is made in the hemispherical head section.

(e) Category B joints of solid elliptical, torispherical, or conical heads to layered shell sections shall be of Type (1) or (2) of Table UW-12. Transitions shall be as shown in Figure ULW-17.2, sketch (c), (d-1), (d-2), (e), or (f).

(f) Category C joints of solid flat heads and tubesheets to layered shell sections shall be of Type (1) or (2) of Table UW-12 as indicated in Figure ULW-17.3. Transitions, if applicable, shall be used as shown in Figure ULW-17.1, sketch (c), (d), (e), or (f).

(g) Category C joints attaching solid flanges to layered shell sections and layered flanges to layered shell sections shall be of Type (1) or (2) of Table UW-12 as indicated in Figure ULW-17.4.

(h) Category A joints of layered hemispherical heads to layered shell sections shall be of Type (1) or (2) of Table UW-12 with a transition as shown in Figure ULW-17.5, sketch (a-1) or (a-2).

(i) Category B joints of layered conical heads to layered shell sections shall be of Type (1) or (2) of Table UW-12 with transitions as shown in Figure ULW-17.5, sketch (b-1).

(j) Category B joints of layered shells to layered shell sections or layered shell sections to solid heads or shells may be butt joints as shown in Figure ULW-17.6, sketches (c), (d), and (e), or step welds as shown in Figure ULW-17.6, sketches (a), (b), (f), and (g).

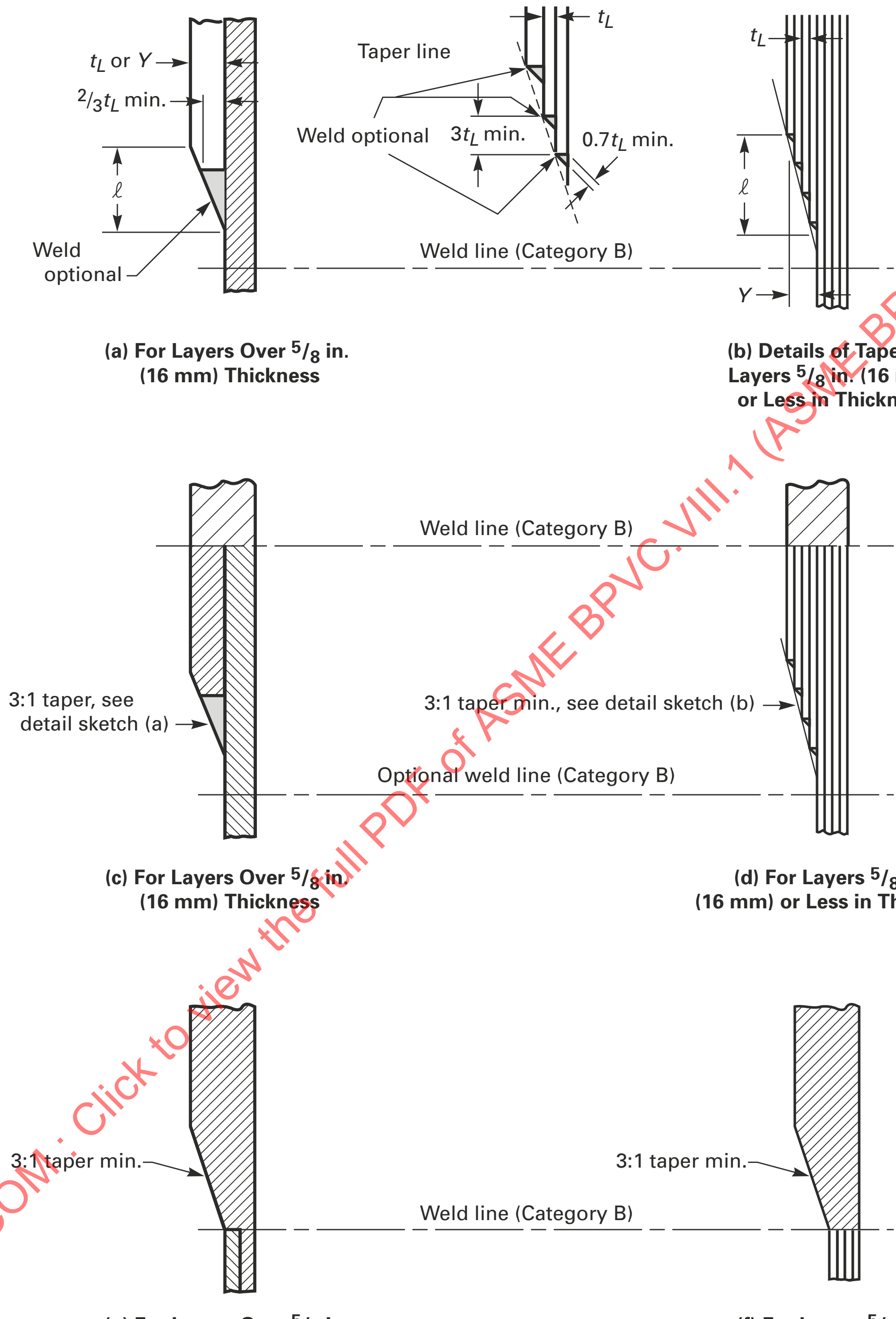
(k) Category D joints of solid nozzles, manholes, and other connections to layered shell or layered head sections shall be full penetration welds as shown in Figure ULW-18.1 except as permitted in sketch (i), (j), (k), or (l). Category D joints between layered nozzles and shells or heads are not permitted.

(l) When layers of Category A joints as shown in Figure ULW-17.2, sketches (a), (b-1), (b-2), and (b-3) and Figure ULW-17.5, sketches (a-1) and (a-2) are welded with fillet welds having a taper less than 3:1, the longitudinal load resisted by the weld shall not exceed the allowable load as defined in UW-18(d). No resistance due to friction shall be used in determining the longitudinal load at the welds. The longitudinal load resisted by the weld shall consider the load transferred from the remaining outer layers.

ULW-18 NOZZLE ATTACHMENTS AND OPENING REINFORCEMENT

(a) All openings, except as provided in (b) below, shall meet the requirements for reinforcing per UG-36 through UG-46. All reinforcements required for openings shall be integral with the nozzle or provided in the layered section or both. Additional layers may be included for required reinforcement. Some acceptable nozzle geometries and attachments are shown in Figure ULW-18.1. Openings are not permitted in the shell sections of helically wound interlocking strip construction.

Figure ULW-17.1
Transitions of Layered Shell Sections



(a) For Layers Over $^5/_8$ in. (16 mm) Thickness

(b) Details of Taper for Layers $^5/_8$ in. (16 mm) or Less in Thickness

(c) For Layers Over $^5/_8$ in. (16 mm) Thickness

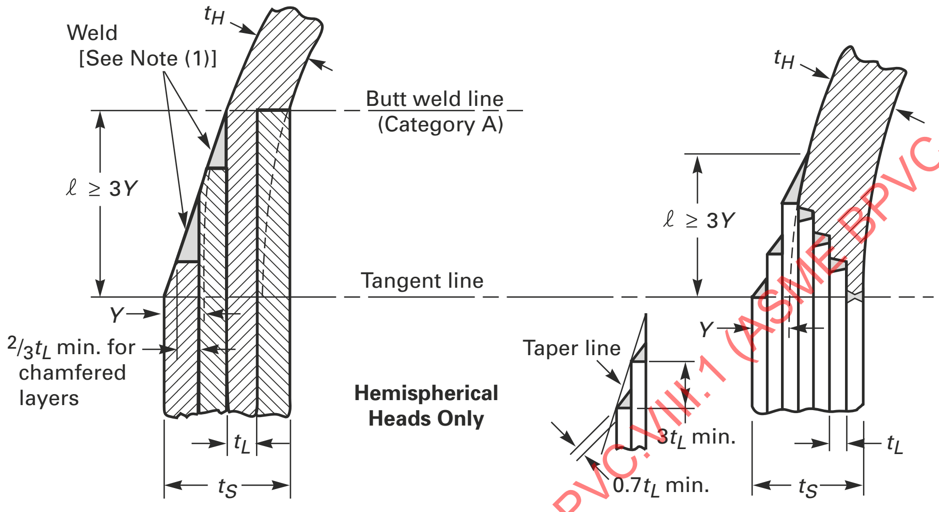
(d) For Layers $^5/_8$ in. (16 mm) or Less in Thickness

(e) For Layers Over $^5/_8$ in. (16 mm) Thickness

(f) For Layers $^5/_8$ in. (16 mm) or Less in Thickness

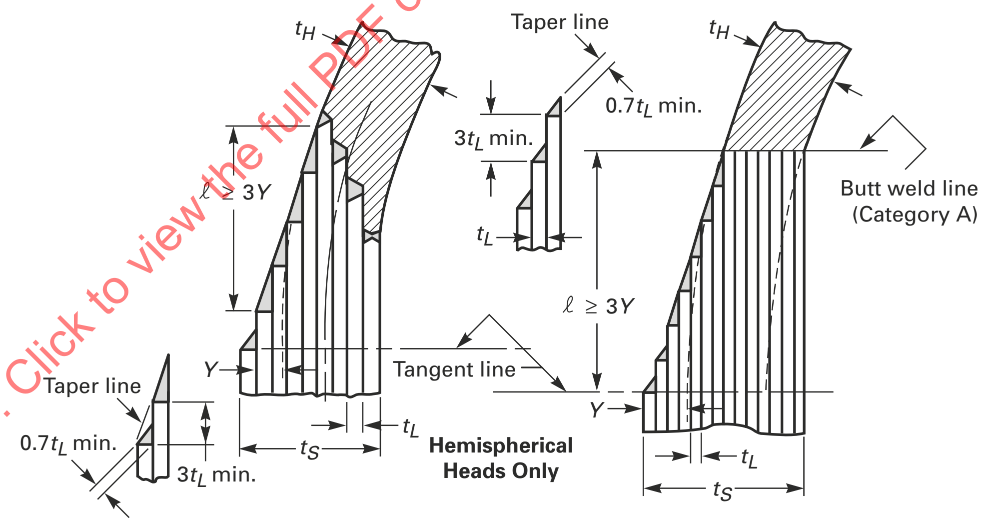
GENERAL NOTES:
(a) Taper may be inside or outside or both.
(b) $\ell \geq 3Y$, where ℓ is required length of taper and Y is the offset. t_L is the thickness of one layer. The length of required taper may include the width of the weld. The transition may be on either or both sides.

Figure ULW-17.2
Some Acceptable Solid Head Attachments to Layered Shell Sections



(a) For Layers Over $^5/_8$ in. (16 mm) in Thickness

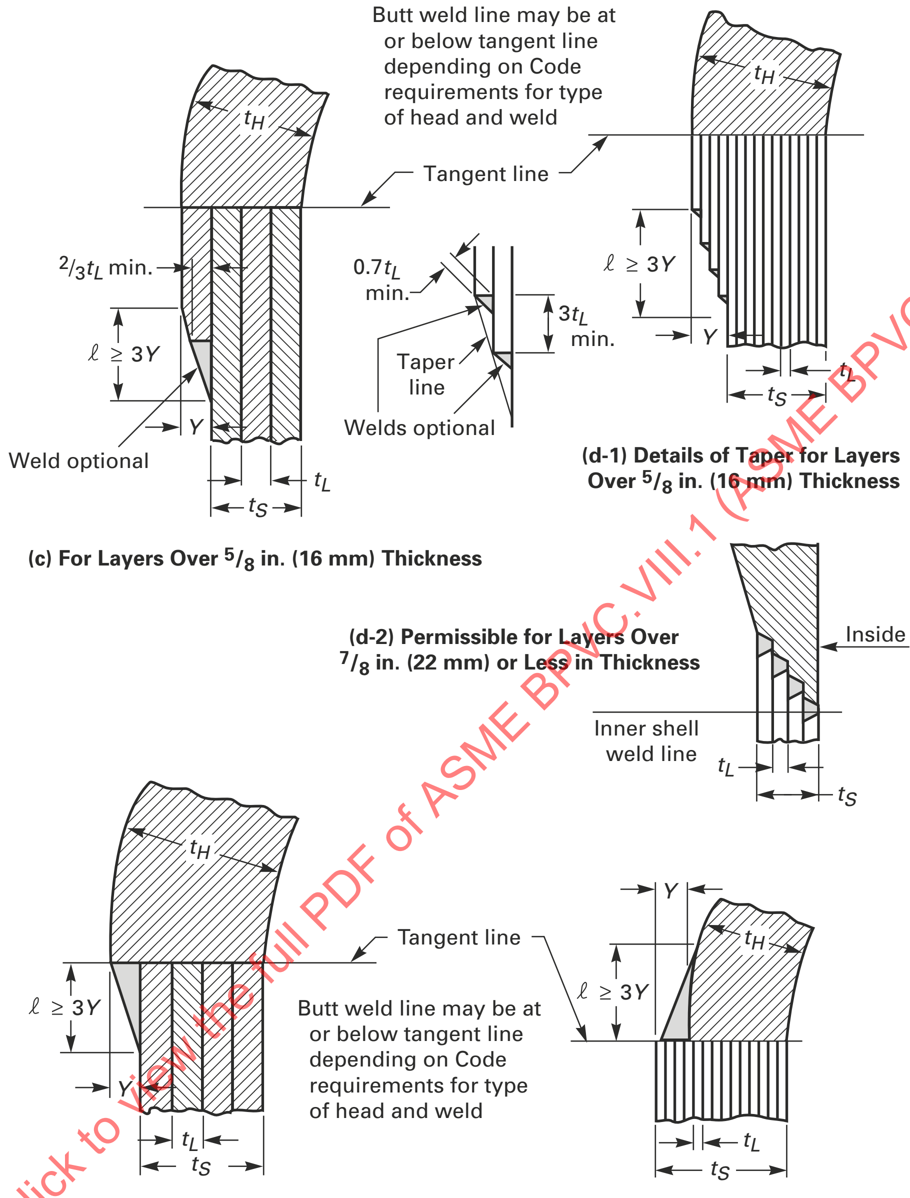
(b-1) Details of Taper for Layers $^7/_8$ in. (22 mm) or Less in Thickness



(b-2) Details of Taper for Layers $^7/_8$ in. (22 mm) or Less in Thickness

(b-3) Details of Taper for Layers $^5/_8$ in. (16 mm) or Less in Thickness

Figure ULW-17.2
Some Acceptable Solid Head Attachments to Layered Shell Sections (Cont'd)



(c) For Layers Over $^5/_8$ in. (16 mm) Thickness

(d-1) Details of Taper for Layers Over $^5/_8$ in. (16 mm) Thickness

(d-2) Permissible for Layers Over $^7/_8$ in. (22 mm) or Less in Thickness

(e) For Layers $^5/_8$ in. (16 mm) or Less in Thickness [See Note (2)]

(f) For Layers of Any Thickness [See Note (3)]

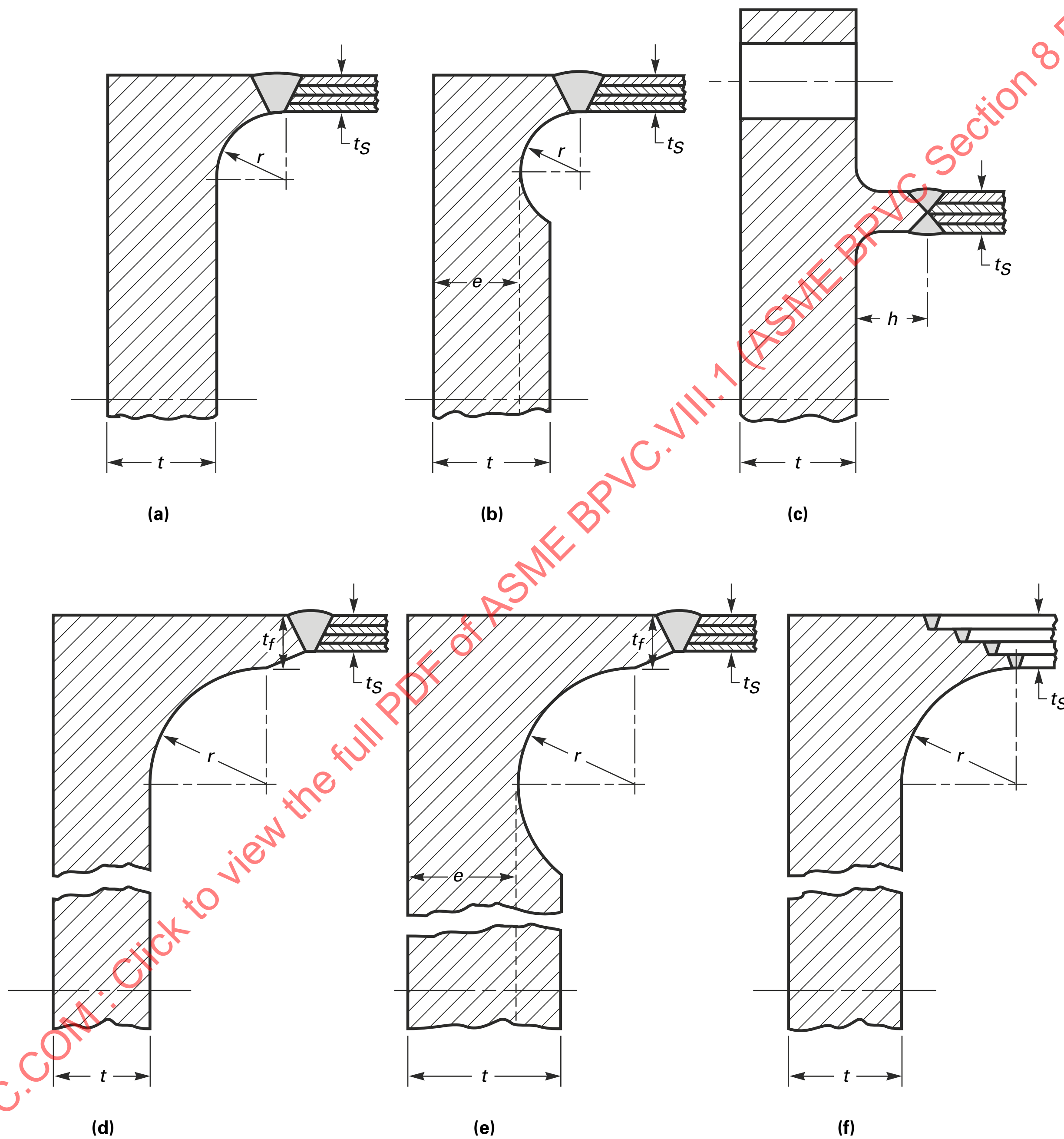
Legend:

t_H = thickness of head at joint
t_L = thickness of one layer
t_S = thickness of layered shell
Y = offset

GENERAL NOTE: In all cases, ℓ shall not be less than $3Y$. The shell centerline may be on either side of the head centerline by a maximum of $\frac{1}{2}(t_S - t_H)$. The length of required taper may include the width of the weld.

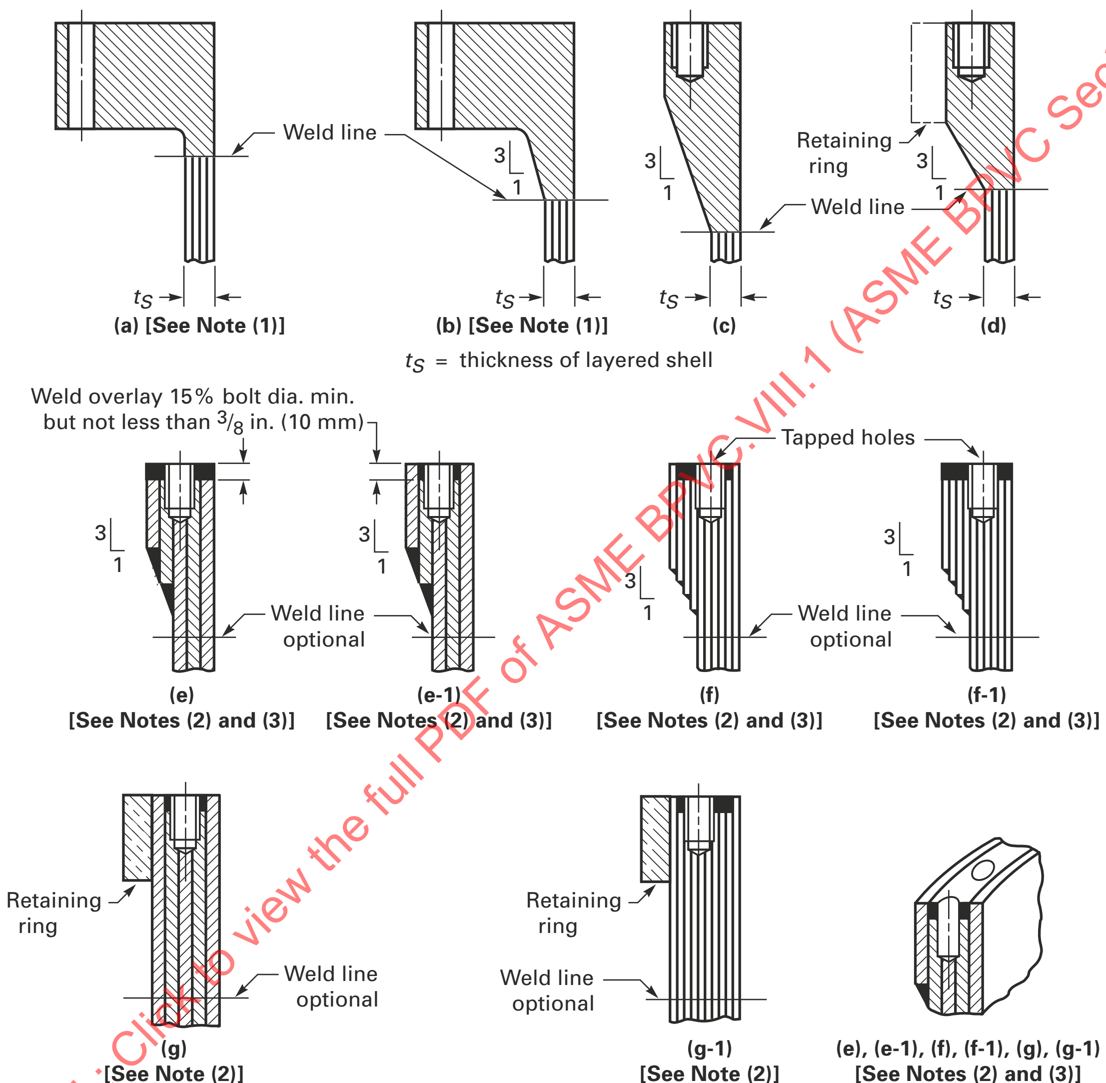
NOTES:
(1) Actual thickness shall not be less than theoretical head thickness.
(2) In sketch (e), Y shall not be larger than t_L.
(3) In sketch (f), Y shall not be larger than $\frac{1}{2}t_S$.

Figure ULW-17.3
Some Acceptable Flat Heads and Tubesheets With Hubs Joining Layered Shell Sections



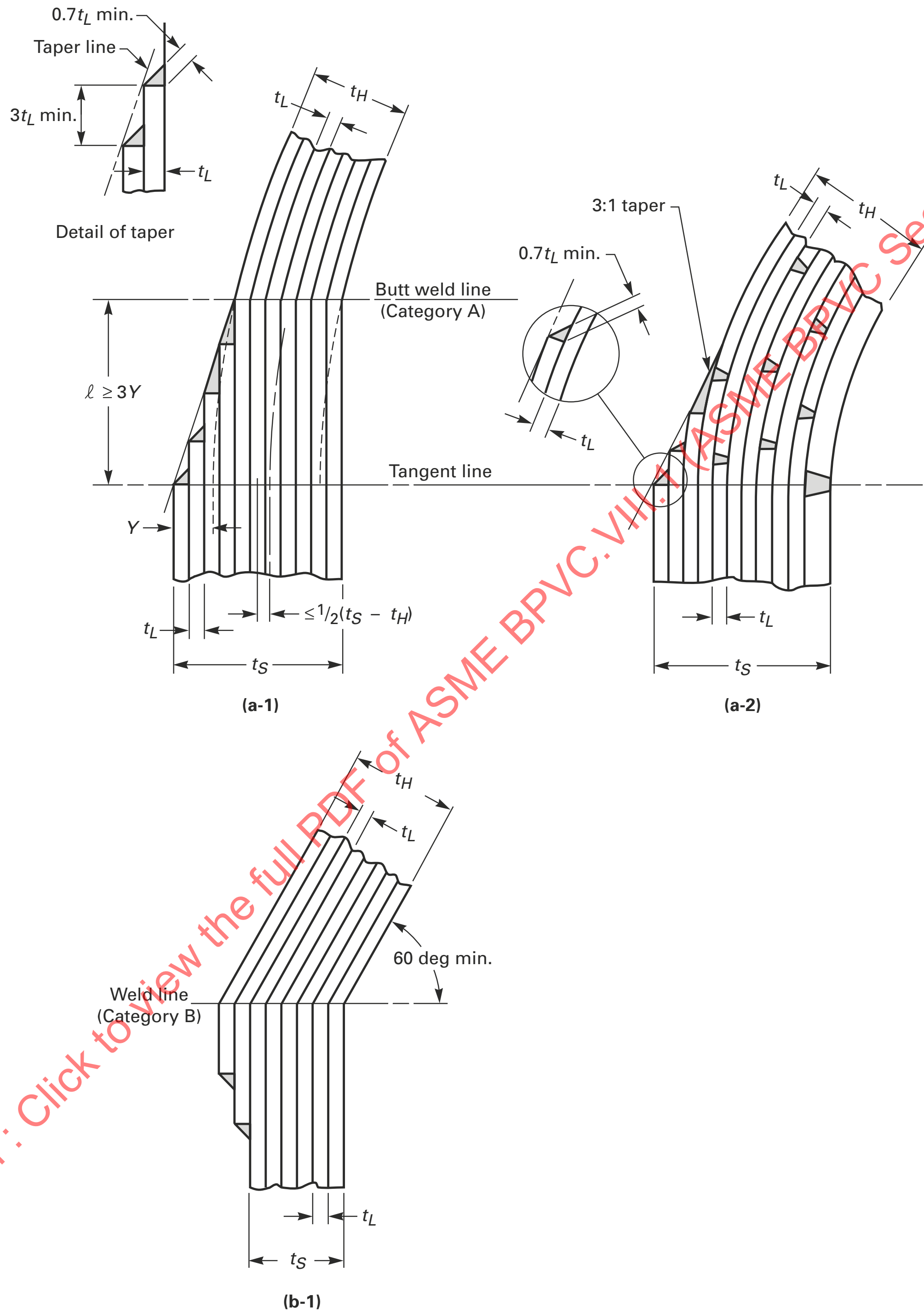
GENERAL NOTES:
(a) t_s = thickness of layered shell [see ULW-17(f)]
(b) t = thickness of flat head or tubesheet [see UG-34]
(c) For all other dimensions, see Figure UW-13.3.

Figure ULW-17.4
Some Acceptable Flanges for Layered Shells



NOTES:
(1) For sketches (a) and (b), see Mandatory Appendix 2, Figure 2-4 for all dimensions and requirements.
(2) The following limitations apply to sketches (e), (e-1), (f), (f-1), (g), and (g-1):
(a) The weld overlay shall tie the overlay, the overwraps, and layers together.
(b) The bolt circle shall not exceed the outside diameter of the shell.
(3) For sketches (e), (e-1), (f), and (f-1), the angle of transition and size of fillet welds are optional. The bolt circle diameter shall be less than the outside diameter of the layered shell.

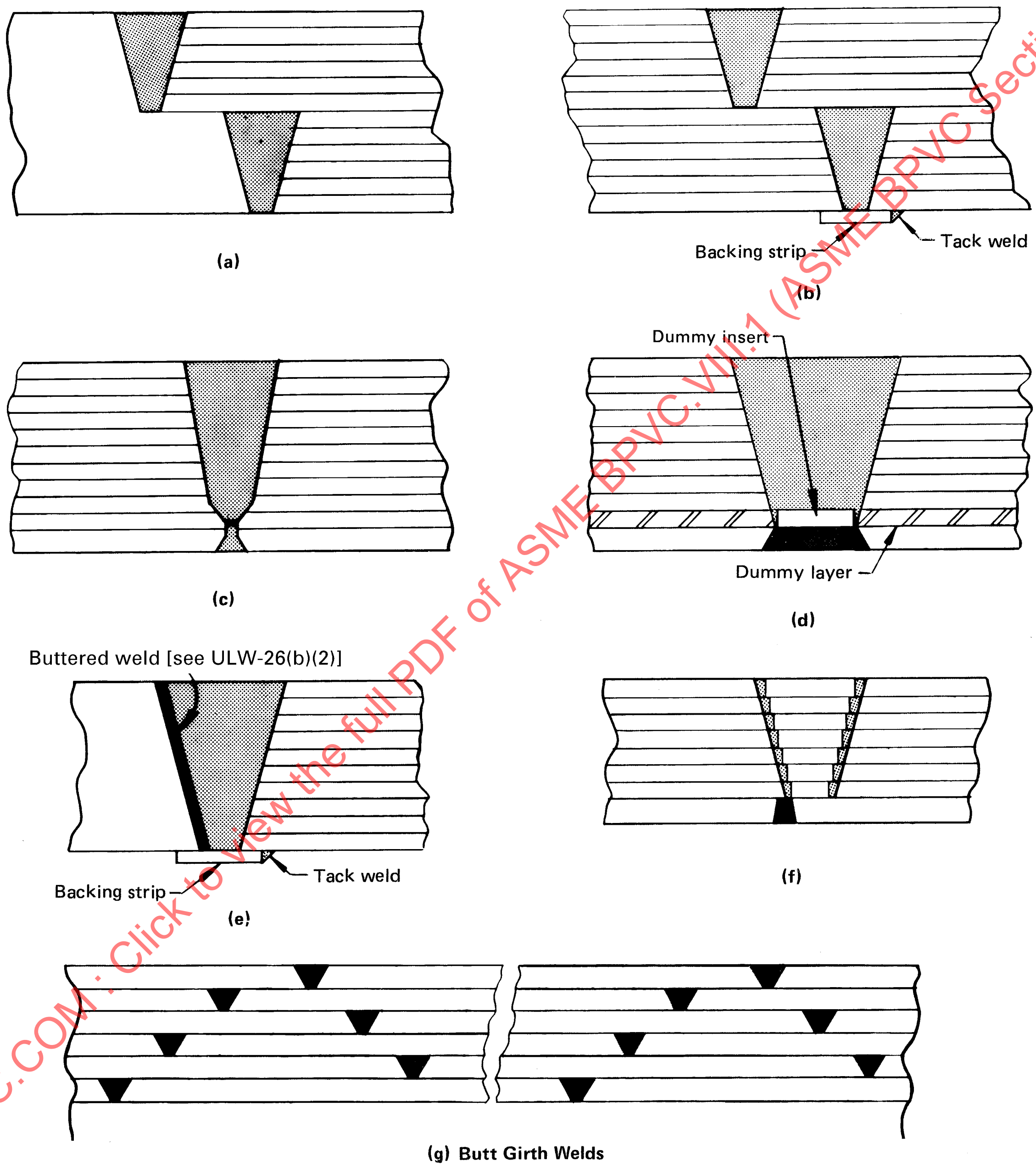
Figure ULW-17.5
Some Acceptable Layered Head Attachments to Layered Shells



Legend:

t_H = thickness of layered head
t_L = thickness of one layer
t_S = thickness of layered shell
Y = offset

Figure ULW-17.6
Some Acceptable Welded Joints of Layered-to-Layered and Layered-to-Solid Sections



(b) Openings, NPS 2 (DN 50) and smaller, need not be reinforced when installed in layered construction, but shall be welded on the inside as shown in Figure ULW-18.1, sketch (j). The nozzle nominal wall thickness shall not be less than Schedule 80 pipe as fabricated, in addition to meeting the requirements of UG-45.

(c) Openings up to and including 6 in. (150 mm) nominal pipe size may be constructed as shown in Figure ULW-18.1, sketches (k) and (l). Such partial penetration weld attachments may only be used for instrumentation openings, inspection openings, etc., on which there are no external mechanical loadings, provided the following requirements are met.

(1) The requirements for reinforcing specified in (a) above apply except that the diameter of the finished openings in the wall shall be d' as specified in Figure ULW-18.1, sketches (k) and (l), and the thickness t_r is the required thickness of the layered shells computed by the design requirements.

(2) Additional reinforcement, attached to the inside surface of the inner shell, may be included after the corrosion allowance is deducted from all exposed surfaces. The attachment welds shall comply with UW-15, UW-16, and Figure ULW-18.1, sketch (k) or (l).

(3) Metal in the nozzle neck available for reinforcement shall be limited by the boundaries specified in UG-40(c), except that the inner layer shall be considered the shell.

(**25**) *(d)* Openings greater than NPS 2 (DN 50) may be constructed as shown in Figure ULW-18.1, sketch (i). The requirements for reinforcing specified in (a) above apply except that:

(1) the diameter of the finished openings in the wall shall be d' as specified in Figure ULW-18.1, sketch (i); and the thickness t_r is the required thickness of the layered shells computed by the design requirements;

(2) additional reinforcement may be included in the solid hub section as shown in Figure ULW-18.1, sketch (i);

(3) metal in the nozzle neck available for reinforcement shall be limited by the boundaries specified in UG-40(c), except that the inner layer shall be considered the shell.

(e) The bolt circle in a layered flange shall not exceed the outside diameter of the shell. Weld overlay as shown in Figure ULW-17.4, sketches (e), (e-1), (f), (f-1), (g), and (g-1) shall be provided to tie the overwraps and layers together.

ULW-20 WELDED JOINT EFFICIENCY

When the nondestructive examinations outlined in ULW-50 through ULW-57 have been complied with, the weld joint efficiency for design purposes shall be 100%.

ULW-22 ATTACHMENTS

Attachments to a single layer of a layered vessel shall be given consideration in meeting the requirements of UG-22. Outside layers are especially critical when support lugs, skirts, or jacket closures are welded to them. Only the thickness of the layer to which the attachment is welded shall be considered in calculating the stress near the attachment, except where provisions are made to transfer the load to other layers. For some acceptable supports, see Figure ULW-22. Jacketed closures shall be designed in accordance with Part UJV except that:

(a) partial jackets as shown in Section VIII, Division 2, Figure 4.11.2 are not permitted on layered sections;

(b) provisions shall be made for extending layer vents through the jacket (see ULW-76).

ULW-26 POSTWELD HEAT TREATMENT

(a) When required, pressure parts shall be postweld heat treated in accordance with the rules prescribed in UCS-56, UG-85, UW-10, UW-40, and UHT-56; however, layered vessels or layered vessel sections need not be postweld heat treated, provided the requirements of (b) below are met.

(b) Unless required by UW-2, layered vessels or layered vessel sections need not be postweld heat treated when welded joints connect a layered section to a layered section, or a layered section to a solid wall, provided all of the following conditions are met.

(1) The thickness referred to in UCS-56 and UHT-56 is the thickness of one layer. Should more than one thickness of layer be used, the thickness of the thickest layer shall govern.

(2) The finished joint preparation of a solid section which is required to be postweld heat treated under the provisions of UCS-56 or UHT-56, shall be provided with a buttered[61] layer of at least $^1/_8$ in. (3 mm) thick welding material not requiring postweld heat treatment. Solid sections of P-No. 1 materials need not have this buttered layer. Postweld heat treatment of the buttered solid section shall then be performed prior to attaching to the layered sections. Postweld heat treatment following attachment to the layered section is not required unless the layered section is required to be postweld heat treated.

(3) Multipass welding is used and the weld layer thickness is limited to $^3/_8$ in. (10 mm) maximum. When materials listed in Part UHT are used, the last pass shall be given a temper bead welding technique[62] treatment except for 5%, 8%, and 9% nickel steels.

(4) For lethal service [UW-2(a)], see ULW-1 Scope.

WELDING

ULW-31 WELDED JOINTS

The design of welded joints of layered vessels shall be in accordance with ULW-17. Welded joints of Table UW-12, Type Nos. (3), (4), (5), and (6) are not permitted in layered vessels, except as provided for in ULW-17(b)(2).

Figure ULW-18.1
Some Acceptable Nozzle Attachments in Layered Shell Sections

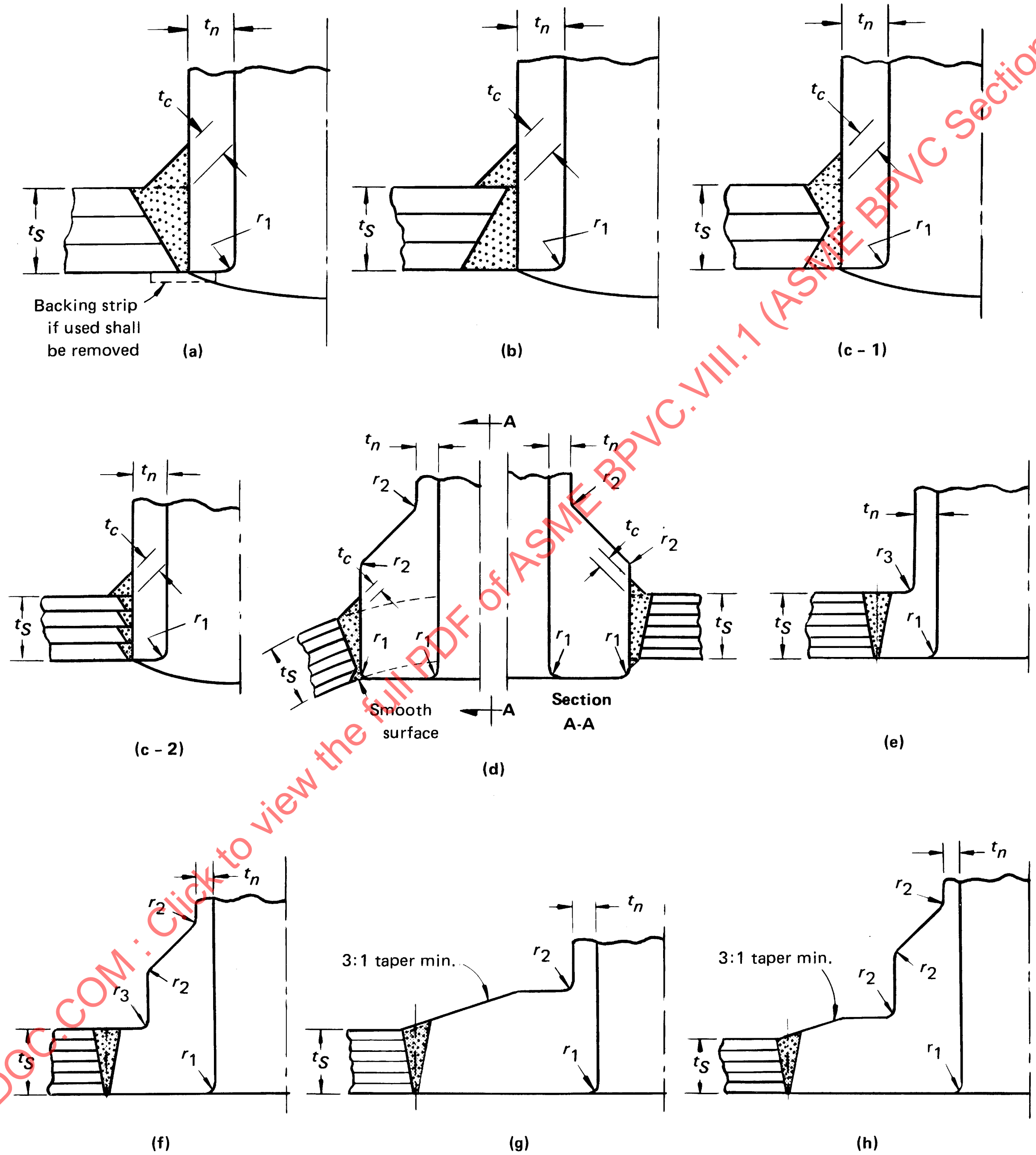
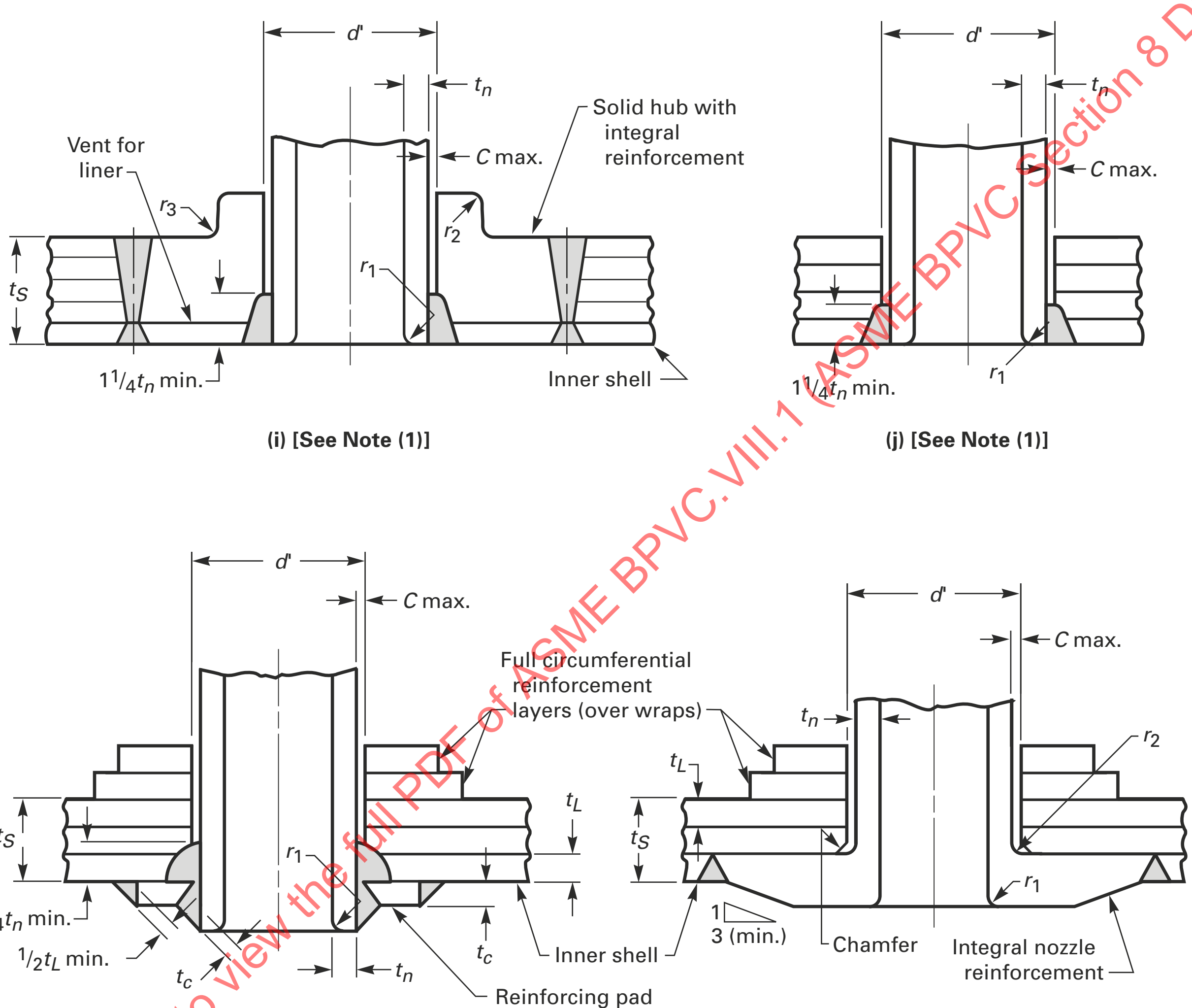


Figure ULW-18.1
Some Acceptable Nozzle Attachments in Layered Shell Sections (Cont'd)



(i) [See Note (1)]

(j) [See Note (1)]

(k) [See Note (1)]

(l) [See Note (1)]

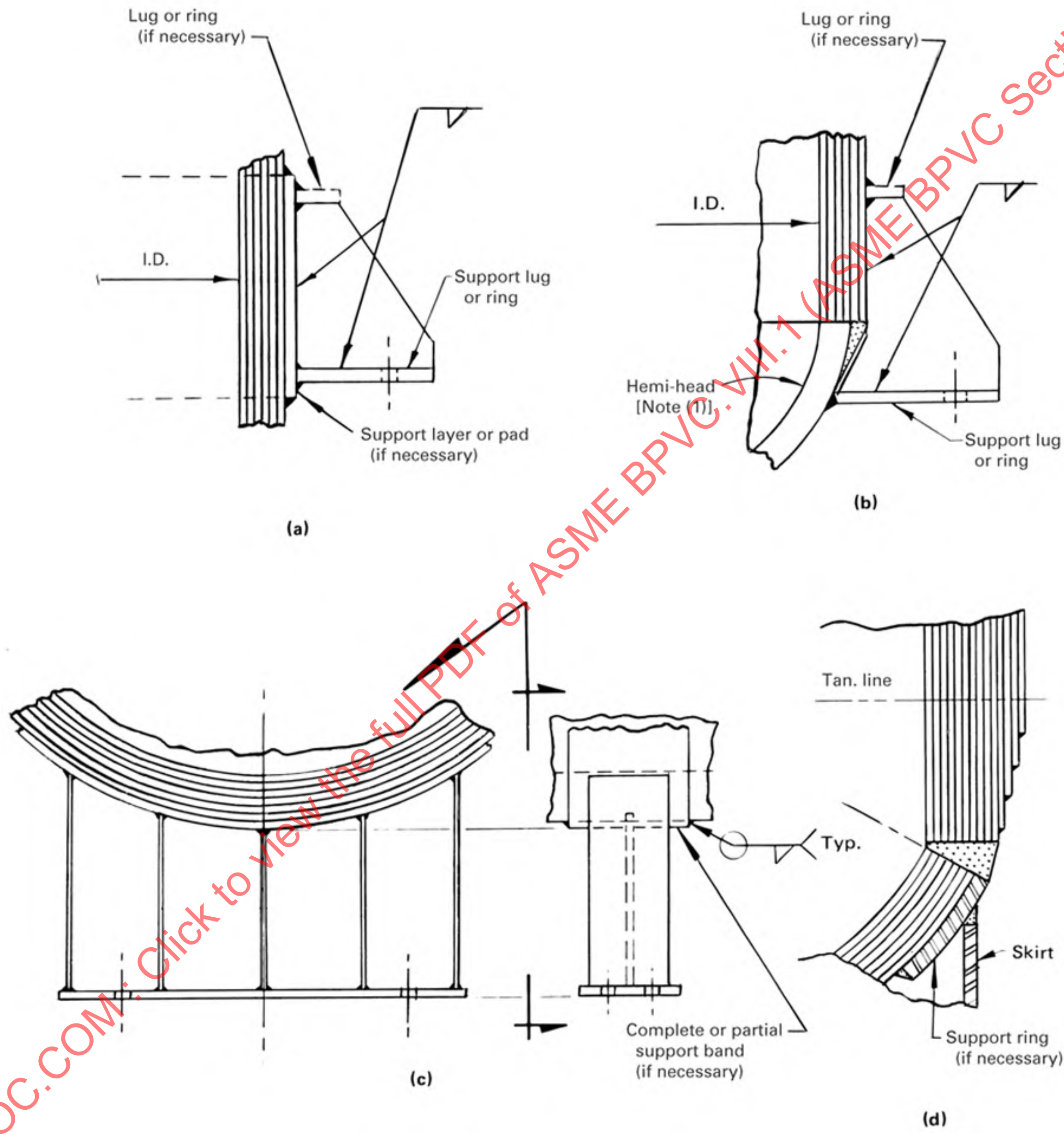
Legend:

C max.	=	$^1/_8$ in. (3 mm) radial clearance between nozzle neck and vessel opening
d'	=	finished opening in the wall (refer to ULW-18 for maximum permissible diameter)
r_1 min.	=	$^1/_4 t_n$ or $^1/_8$ in. (3 mm), whichever is less
r_2	=	$^1/_4$ in. (6 mm) minimum
r_3 min.	=	$^1/_4 t_n$ or $^3/_4$ in. (19 mm), whichever is less
t_c	=	not less than $^1/_4$ in. (6 mm) or 0.7 of the smaller of $^3/_4$ in. (19 mm) or t_n
t_L	=	thickness of one layer
t min.	=	the smaller of $^3/_4$ in. (19 mm) or t_n
t_n	=	nominal thickness of nozzle wall
t_S	=	thickness of layered shell

NOTE:

(1) Provide means, other than by seal welding, to prevent entry of external foreign matter into the annulus between the layers and the nozzle neck O.D. for sketches (i), (j), (k), and (l).

Figure ULW-22
Some Acceptable Supports for Layered Vessels



NOTE:
(1) For other than hemi-heads, special consideration shall be given to the discontinuity stress.

ULW-32 WELDING PROCEDURE QUALIFICATION

Welding procedure qualifications shall be in accordance with Section IX except as modified herein.

(a) The minimum and maximum thicknesses qualified by procedure qualification test plates shall be as shown in Section IX, Tables QW-451.1 through QW-451.4, except that:

(1) for the longitudinal joints of the layer section of the shell, the qualification shall be based upon the thickness of the thickest individual layer, exclusive of the inner shell or inner head;

(2) for circumferential joint procedure qualification, the thickness of the layered test plate need not exceed 3 in. (75 mm), shall consist of at least 2 layers, but shall not be less than 2 in. (50 mm) in thickness;

(3) for circumferential weld joints made individually for single layers and spaced at least one layer thickness apart, the procedure qualification for the longitudinal joint applies.

(b) The longitudinal weld joint of the inner shell or inner head and the longitudinal weld joint of layer shell or layer head shall be qualified separately except if of the same P-Number material. The weld gap of the longitudinal layer weld joint shall be the minimum width used in the procedure qualification for layers $^7/_8$ in. (22 mm) and less in thickness.

(c) The circumferential weld joint of the layered to layered sections shall be qualified with a simulated layer test plate as shown in Figure ULW-32.1 for layer thicknesses $^7/_8$ in. (22 mm) and under. A special type of joint tensile specimen shall be made from the layer test coupon as shown in Figure ULW-32.2. (See also Figure ULW-32.4.) Face and root bend specimens shall be made of both the inner and outer weld to the thickness of the layer by cutting the weld to the layer thickness.

(d) The circumferential weld joint of the layer shell for layer thicknesses $^7/_8$ in. (22 mm) and under to the solid head, flange, or end closure shall be qualified with a simulated layer test coupon as shown in Figure ULW-32.1 wherein the one side of the test coupon is solid throughout its entire thickness. A special type of joint tensile specimen shall be made from the test coupon as shown in Figure ULW-32.3. (See also Figure ULW-32.4.) Face and root bend specimens shall be made of both the inner and outer weld to the thickness of the layer by slicing the weld and solid portion to the layer thickness.

ULW-33 PERFORMANCE QUALIFICATION

Welding shall be performed only by welders and welding operators who have been qualified as given in Section IX. The minimum and maximum thicknesses qualified by any welder test plate shall be as shown on Section IX, QW-452 tables.

NONDESTRUCTIVE EXAMINATION OF WELDED JOINTS

ULW-50 GENERAL

The rules of the following paragraphs apply specifically to the nondestructive examination of pressure vessels and vessel parts that are fabricated using layered construction.

ULW-51 INNER SHELLS AND INNER HEADS

Category A and B joints in the inner shells of layered shell sections, and in the inner heads of layered heads before application of the layers, shall be examined throughout their entire length by radiography and meet the requirements of UW-51.

ULW-52 LAYERS — WELDED JOINTS

(a) Category A joints in layers $^1/_8$ in. (3 mm) through $^5/_{16}$ in. (8 mm) in thickness welded to the previous surface shall be examined for 100% of their length in accordance with Mandatory Appendix 6 by the magnetic particle method using direct current only when the material is ferromagnetic. The liquid penetrant method in accordance with Mandatory Appendix 8 shall be used when the material is nonferromagnetic.

(b) Category A joints in layers over $^5/_{16}$ in. (8 mm) through $^5/_8$ in. (16 mm) in thickness welded to the previous surface shall be examined for 100% of their length in accordance with Mandatory Appendix 6 by the magnetic particle method using direct current only when the material is ferromagnetic. The liquid penetrant method in accordance with Mandatory Appendix 8 shall be used when the material is nonferromagnetic. In addition, these joints shall be examined for 10% of their length at random in accordance with Mandatory Appendix 12 ultrasonic method except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB. The random spot examination shall be performed as specified in ULW-57.

(c) Category A joints in layers over $^5/_8$ in. (16 mm) through $^7/_8$ in. (22 mm) in thickness welded to the previous surface shall be examined for 100% of their length in accordance with Mandatory Appendix 12 ultrasonic method except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB.

(d) Category A joints in layers not welded to the previous surface shall be examined before assembly for 100% of their length by radiography and meet the requirements of UW-51.

(e) Welds in spirally wound strip construction with a winding or spiral angle of 75 deg or less measured from the vessel axial centerline shall be classified as Category A joints and examined accordingly.

Figure ULW-32.1
Solid-to-Layered and Layered-to-Layered Test Plates

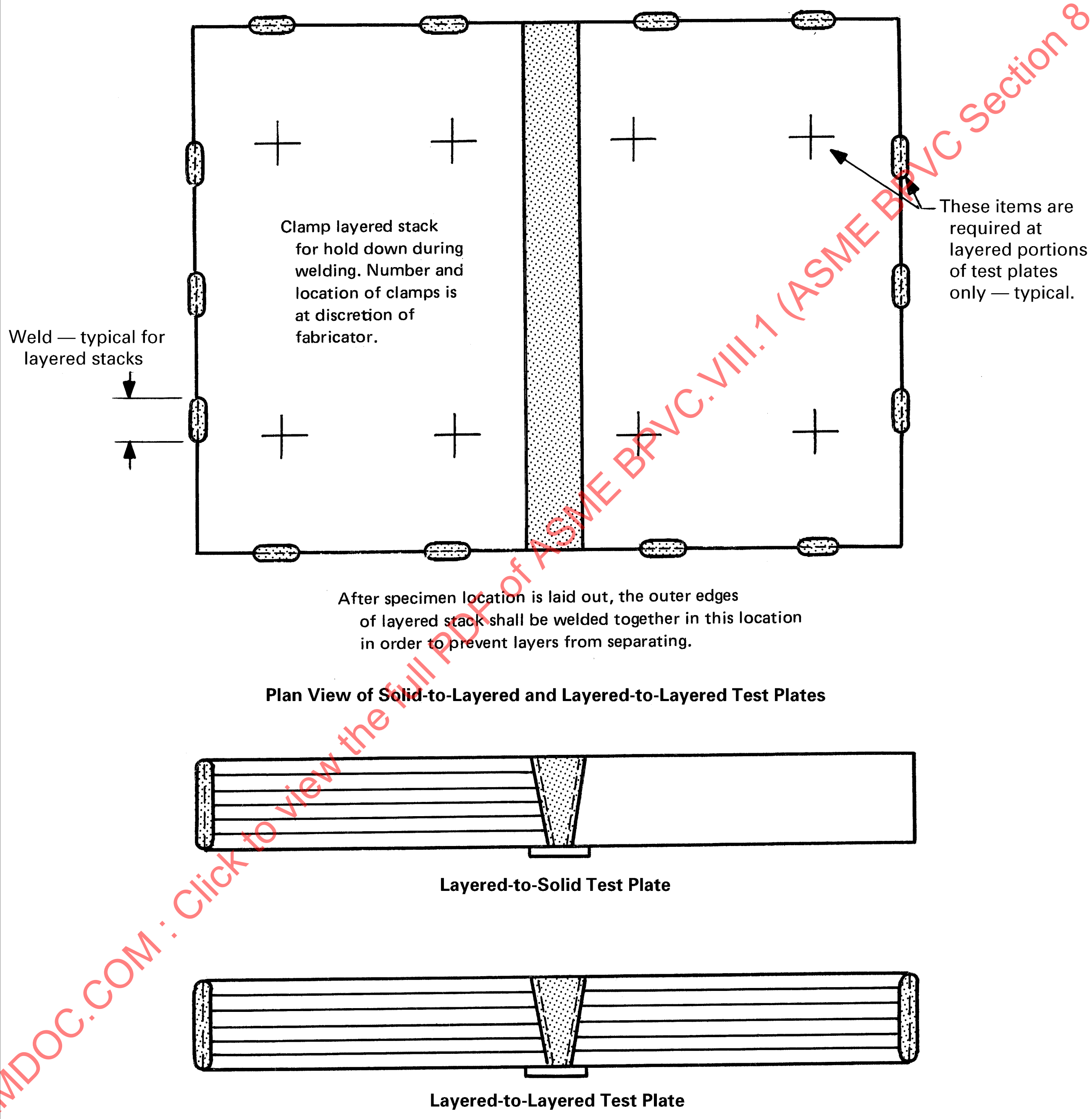
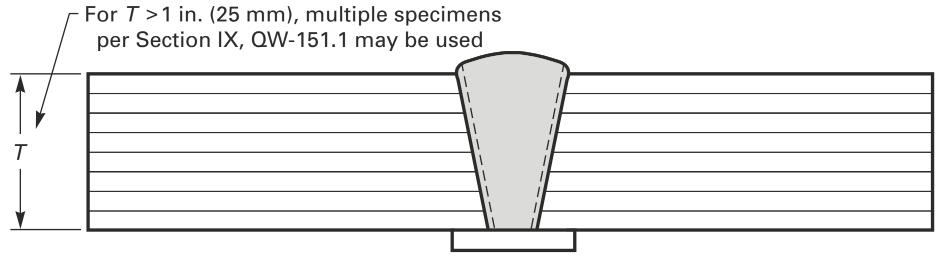


Figure ULW-32.2



ULW-53 LAYERS — STEP WELDED GIRTH JOINTS

(a) Category B joints in layers $^1/_8$ in. (3 mm) through $^5/_{16}$ in. (8 mm) in thickness shall be examined for 10% of their length in accordance with Mandatory Appendix 6 by the magnetic particle method using direct current only when the material is ferromagnetic. The liquid penetrant method in accordance with Mandatory Appendix 8 shall be used when the material is nonferromagnetic. The random spot examination shall be performed as specified in ULW-57.

(b) Category B joints in layers over $^5/_{16}$ in. (8 mm) through $^5/_8$ in. (16 mm) in thickness shall be examined for 100% of their length in accordance with Mandatory Appendix 6 by the magnetic particle method, using direct current only when the material is ferromagnetic. The liquid penetrant method in accordance with Mandatory Appendix 8 shall be used when the material is nonferromagnetic.

(c) Category B joints in layers over $^5/_8$ in. (16 mm) through $^7/_8$ in. (22 mm) in thickness shall be examined for 100% of their length in accordance with Mandatory Appendix 6 by the magnetic particle method using direct current only when the material is ferromagnetic. The liquid penetrant method in accordance with Mandatory Appendix 8 shall be used when the material is nonferromagnetic. In addition these joints shall be examined for 10% of their length in accordance with Mandatory Appendix 12 ultrasonic examination, except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB. The random spot examination shall be performed as specified in ULW-57.

(d) Category B joints in layers over $^7/_8$ in. (22 mm) in thickness shall be examined for 100% of their length in accordance with Mandatory Appendix 12 ultrasonic method except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB.

ULW-54 BUTT JOINTS

(a) Full Thickness Welding of Solid Section to Layered Sections. Category A, B, and D joints attaching a solid section to a layered section of any of the layered thicknesses given in ULW-52 shall be examined by radiography for their entire length in accordance with UW-51.

It is recognized that layer wash[63] or acceptable gaps (see ULW-77) may show as indications difficult to distinguish from slag on the radiographic film. Acceptance shall be based on reference to the weld geometry as shown in Figure ULW-54.1. As an alternative, an angle radiographic technique, as shown in Figure ULW-54.2, may be used to locate individual gaps in order to determine the acceptability of the indication.

(b) Full Thickness Welding of Layered Section to Layered Section. Category A and B joints attaching a layered section to a layered section need not be radiographed after being fully welded when the Category A hemispherical head and Category B welded joints of the inner shell or inner head made after application of the layers have been

Figure ULW-32.3

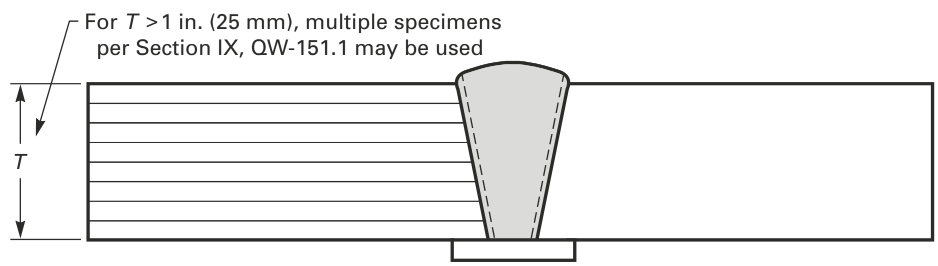
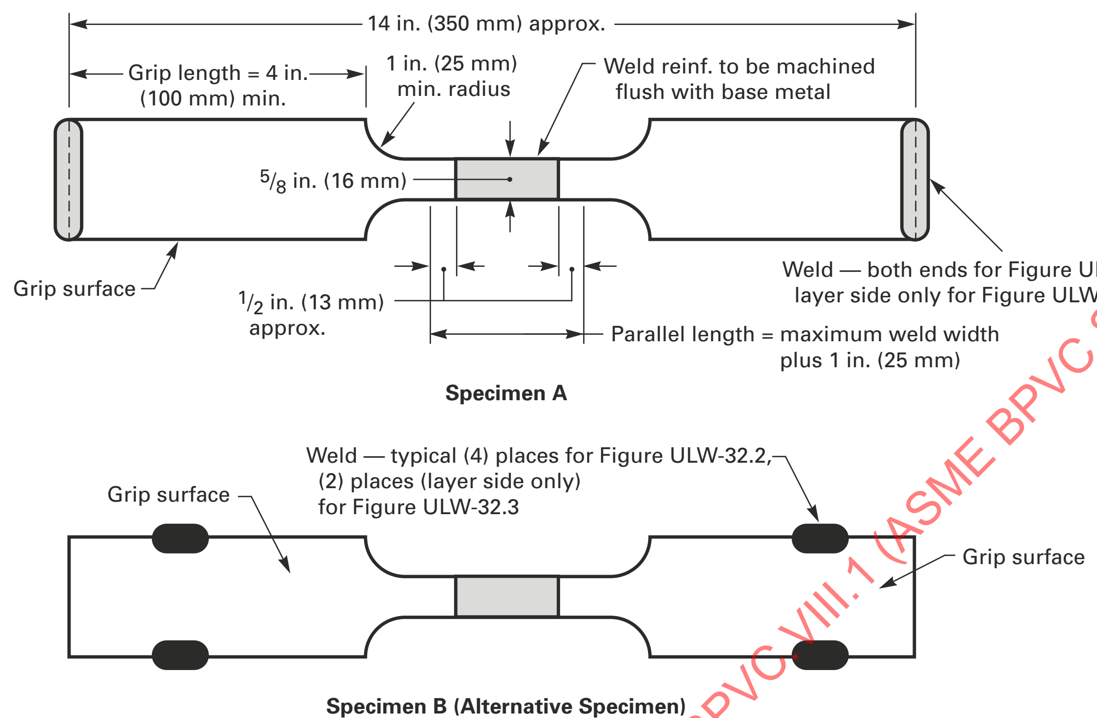


Figure ULW-32.4



GENERAL NOTE: Specimens A and B are plan views of Figures ULW-32.2 and ULW-32.3 and are identical except for locations of grip surfaces and welds. All grip surfaces are to be machined flat.

radiographed in accordance with UW-51. The inner shell or inner head thicknesses need not be radiographed in thicknesses over 7/8 in. (22 mm) if the completed joint is radiographed. Weld joints in the inner shell or inner head welded after application of the layers of the inner shell or inner head weld joints shall be radiographed throughout their entire length and meet the requirements of UW-51.

ULW-55 FLAT HEAD AND TUBESHEET WELD JOINTS

Category C joints attaching layered shells or layered heads to flat heads and tubesheets as shown in Figure ULW-17.3 shall be examined to the same requirements as specified in ULW-53 and ULW-54(a) for Category B joints.

ULW-56 NOZZLE AND COMMUNICATING CHAMBERS WELD JOINTS

Category D joints in layered shells or layered heads not requiring radiographic examination shall be examined by the magnetic particle method in accordance with Mandatory Appendix 6. The partial penetration weld joining liner type nozzle as shown in Figure ULW-18.1, sketches (i), (j), (k), and (l) to layered vessel shells or layered heads shall be examined by magnetic particle or liquid penetrant. Acceptance standards shall meet the requirements of Mandatory Appendix 6 or Mandatory Appendix 8, respectively, for magnetic particle and liquid penetrant examination.

ULW-57 RANDOM SPOT EXAMINATION AND REPAIRS OF WELD (25)

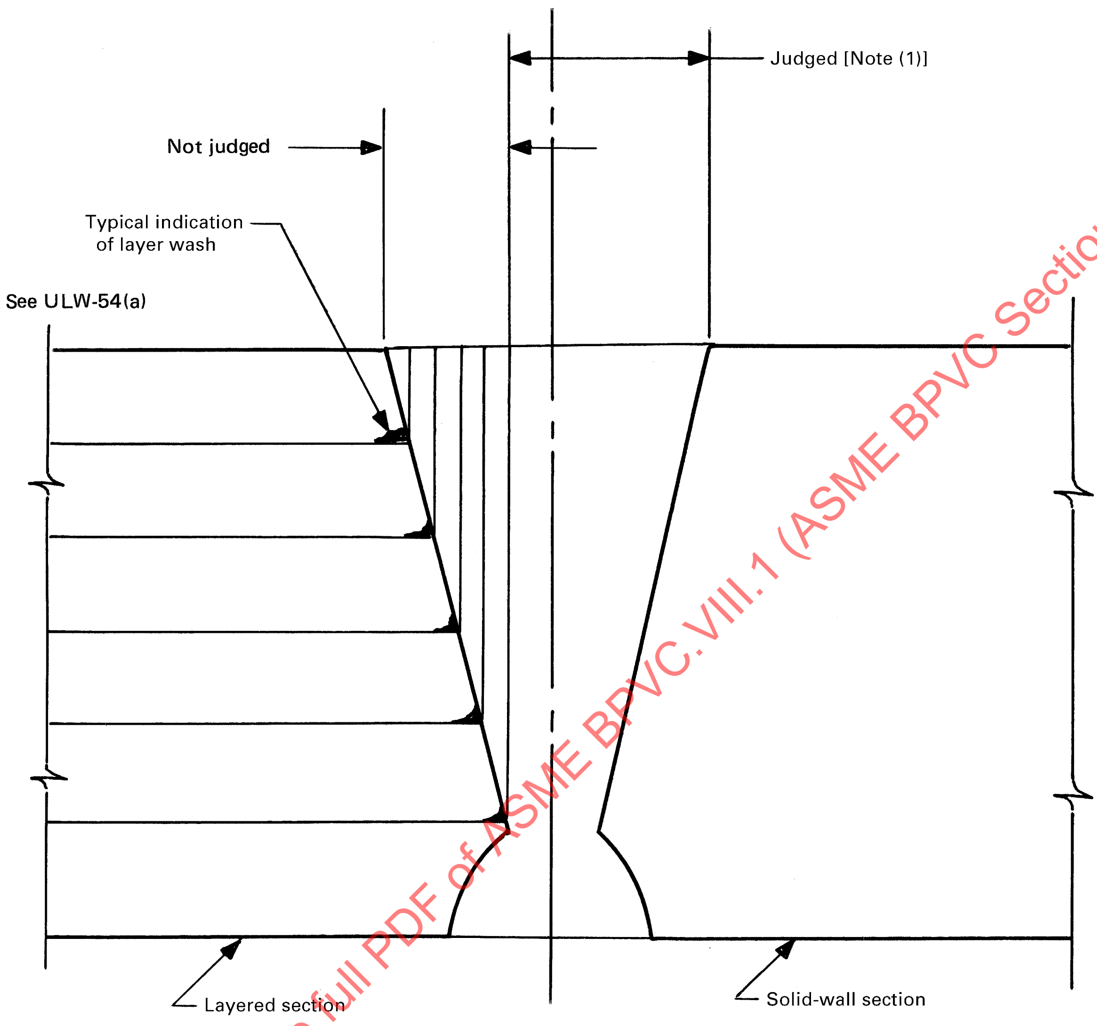
The random ultrasonic examination of ULW-52(b) and ULW-53(c) and random magnetic particle examination of ULW-53(a) shall be performed as follows:

(a) The location of the random spot shall be chosen by the Inspector except that when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the fabricator may select the spot or spots. The minimum length of a spot shall be 6 in. (150 mm).

(b) When any random spot examination discloses welding which does not comply with the minimum quality requirements of ULW-52(b), ULW-53(a), and ULW-53(c), two additional spots of equal length shall be examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or fabricator as provided for the original spot examination.

(c) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of ULW-52(b), ULW-53(a), and ULW-53(c), the entire unit of weld represented shall be

Figure ULW-54.1

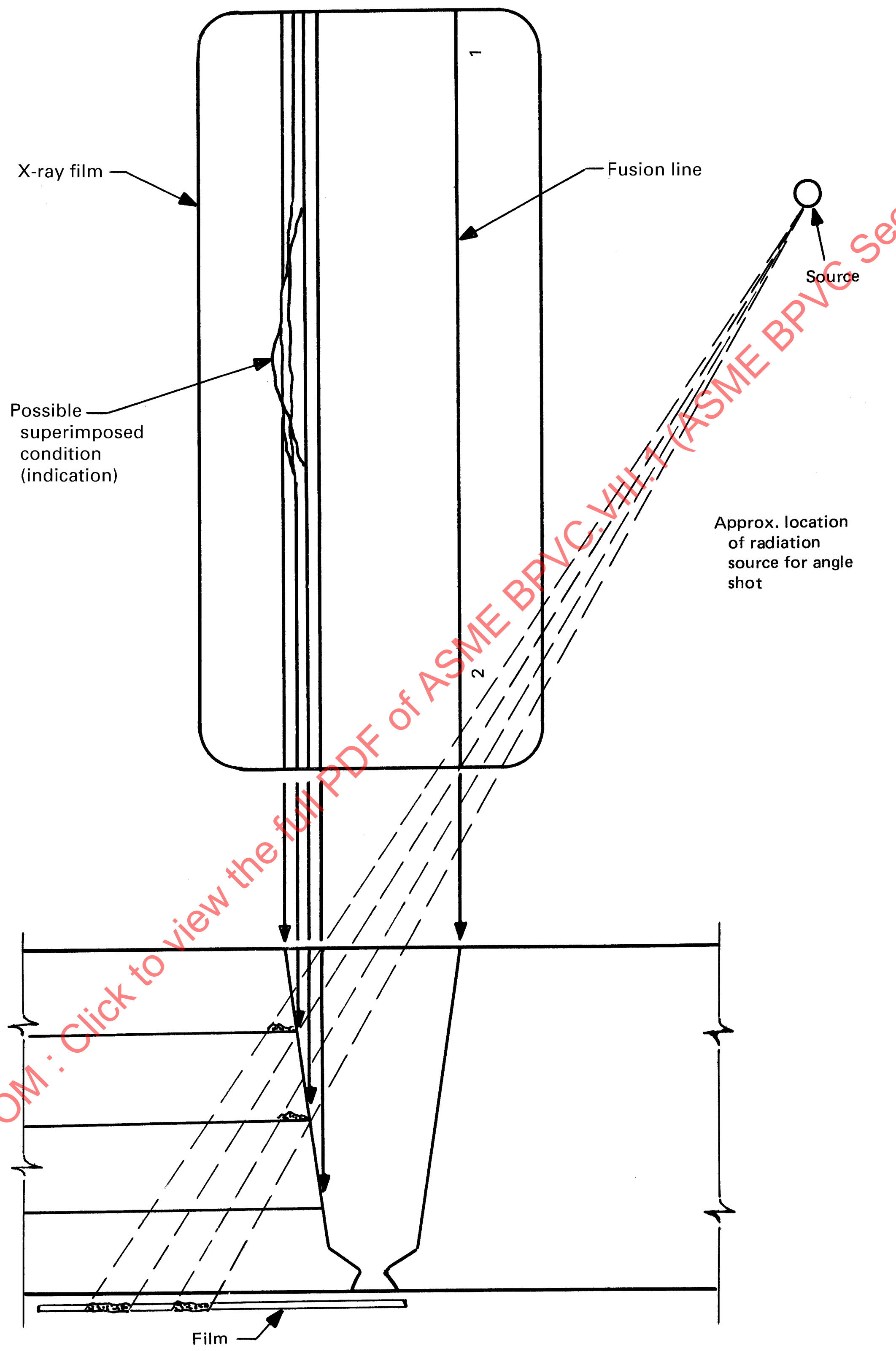


NOTE:
(1) Any indication not in line with layer interface shall be interpreted in accordance with UW-51.

rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the fabricator's option, the entire unit of weld represented shall be completely examined and defects only need be corrected.

(d) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint or the weld repaired areas shall be random spot examined at one location in accordance with the foregoing requirements of ULW-52(b), ULW-53(a), and ULW-53(c).

Figure ULW-54.2



FABRICATION

ULW-75 GENERAL

The rules in the following paragraphs apply to layered shells, layered heads, and layered transition sections that are fabricated by welding and shall be used in conjunction with the general requirements for *Fabrication* in UG-75 through UG-85, with the exception of UG-83.

ULW-76 VENT HOLES

Vent holes shall be provided to detect leakage of the inner shell and to prevent buildup of pressure within the layers as follows:

(a) In each shell course or head segment a layer may be made up of one or more plates. Each layer plate shall have at least two vent holes $^1/_4$ in. (6 mm) minimum diameter. Holes may be drilled radially through the multiple layers or may be staggered in individual layer plates.

(b) For continuous coil wrapped layers, each layered section shall have at least four vent holes $^1/_4$ in. (6 mm) minimum diameter. Two of these vent holes shall be located near each end of the section and spaced approximately 180 deg apart.

(c) The minimum requirement for spirally wound strip layered construction shall be $^1/_4$ in. (6 mm) minimum diameter vent holes drilled near both edges of the strip. They shall be spaced for the full length of the strip and shall be located a distance of approximately $\pi R \tan \theta$ from each other where

R = the mean radius of the shell
θ = the acute angle of spiral wrap measured from longitudinal centerline, deg

If a strip weld covers a vent hole, partially or totally, an additional vent hole shall be drilled on each side of the obstructed hole.

In lieu of the above, holes may be drilled radially through the multiple layers.

(d) Vent holes shall not be obstructed. If a monitoring system is used, it shall be designed to prevent buildup of pressure within the layers.

ULW-77 CONTACT BETWEEN LAYERS

(a) Category A weld joints shall be ground to ensure contact between the weld area and the succeeding layer, before application of the layer.

(b) Category A weld joints of layered shell sections shall be in an offset pattern so that the centers of the welded longitudinal joints of adjacent layers are separated circumferentially by a distance of at least five times the layer thickness.

(c) Category A weld joints in layered heads may be in an offset pattern; if offset, the joints of adjacent layers shall be separated by a distance of at least five times the layer thickness.

(d) After weld preparation and before welding circumferential seams, the height of the radial gaps between any two adjacent layers shall be measured at the ends of the layered shell section or layered head section at right angles to the vessel axis, and also the length of the relevant radial gap in inches shall be measured [neglecting radial gaps of less than 0.010 in. (0.25 mm) as nonrelevant]. An approximation of the area of the gap shall be calculated as indicated in Figure ULW-77.

The gap area A_g shall not exceed the thickness of a layer expressed in square inches. The maximum length of any gap shall not exceed the inside diameter of the vessel. Where more than one gap exists between any two adjacent layers, the sum of the gap lengths shall not exceed the inside diameter of the vessel. The maximum height of any gap shall not exceed $^3/_{16}$ in. (5 mm).

It is recognized that there may be vessels of dimensions wherein it would be desirable to calculate a maximum permissible gap area. This procedure is provided for in Section VIII, Division 2 rules for layered vessels in lieu of the maximum gap area empirically given above, except that the maximum allowable stress S given in Section II, Part D, Subpart 1, Tables 1A and 1B shall be used instead of the stress intensity S_m given in Section II, Part D, Subpart 1, Tables 2A and 2B.

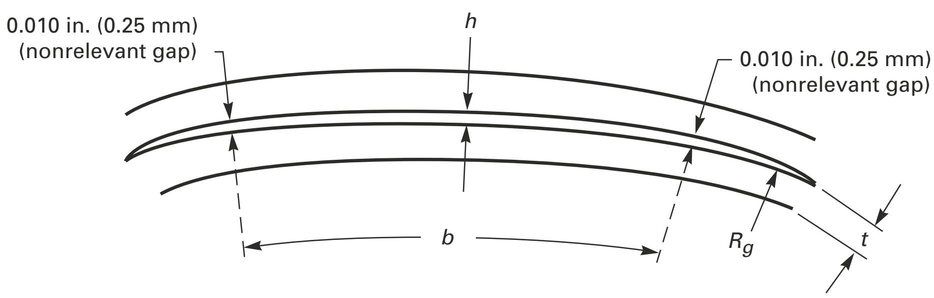
(e) In the case of layered spheres or layered heads, if the gaps cannot be measured as required in (d) above, measurement of gap heights shall be taken through vent holes in each layer course to assure that the height of layer gaps between any two layers does not exceed the gap permitted in (d) above. The spacing of the vent holes shall be such that gap lengths can be determined. In the event an excessive gap height is measured through a vent hole, additional vent holes shall be drilled as required to determine the gap length. There shall be at least one vent hole per layer segment.

ULW-78 ALTERNATIVE TO MEASURING CONTACT BETWEEN LAYERS DURING CONSTRUCTION

As an alternative to ULW-77, the following measurements shall be taken at the time of the hydrostatic test to check on the contact between successive layers, and the effect of gaps which may or may not be present between layers.

(a) The circumference shall be measured at the midpoint between adjacent circumferential joints, or between a circumferential joint and any nozzle in a shell course. Measurements shall be taken at zero pressure, and following application of hydrostatic test pressure, at the design pressure. The difference in measurements shall be averaged for each course in the vessel and the results recorded as average middle circumferential expansion e_m in inches (millimeters).

Figure ULW-77



Legend:

A_g = area of gap (approx.)
= $^2/_3 hb$
b = arc length of relevant radial gap
h = radial gap
R_g = radius of vessel at gap
t = layer thickness

(b) The theoretical circumferential expansion of a solid vessel of the same dimensions and materials as the layered vessel shall be calculated from the following formula:

$$e_{\text{th}} = \frac{1.7\pi P(2R - t_s)^2(2R + t_s)}{8ERt_s}$$

where

E = modulus of elasticity [use 30 × 10^6 psi (200 × 10^6 kPa) for carbon steel]
e_{th} = theoretical circumferential expansion
P = internal design pressure
R = mean radius
= outside radius − $t_s/2$
t_s = wall thickness

(c) Acceptance criteria for circumferential expansion at the design pressure shall be as follows: e_m shall not be less than $0.5e_{th}$.

INSPECTION AND TESTING

ULW-90 GENERAL

The inspection and testing of layered pressure vessels or parts to be marked with the Certification Mark with the U or PRT VIII-1 Designator shall be in accordance with UG-90 through UG-103.

MARKING AND REPORTS

ULW-115 GENERAL

(a) The rules for marking and reports of layered pressure vessels built under Part ULW shall meet the requirements given in UG-115 through UG-120.

(b) In addition, a description of the layered shell and/or layered heads shall be given on the Data Report describing the number of layers, their thickness or thicknesses, and type of construction. See Nonmandatory Appendix W, W-2 and Table W-3 for the use of Nonmandatory Appendix W, Form U-4 Manufacturer's Data Report Supplementary Sheet. An example of the use of Form U-4 illustrating the minimum required data for layered construction is given in Nonmandatory Appendix W, Figure W-3.1.

(c) In addition, the stamping below the Certification Mark and Designator prescribed in UG-116(c) shall be the letters WL to designate layered construction.

PART ULT
ALTERNATIVE RULES FOR PRESSURE VESSELS CONSTRUCTED OF MATERIALS HAVING HIGHER ALLOWABLE STRESSES AT LOW TEMPERATURE

GENERAL

ULT-1 SCOPE

The alternative rules in Part ULT are applicable to pressure vessels or vessel parts that are constructed of materials for which increased design stress values have been established for low temperature applications. When applied, these rules shall be used in conjunction with the requirements in Subsection A and Part UW of Subsection B. The requirements of Subsection C do not apply except when referenced in Part ULT.

ULT-2 CONDITIONS OF SERVICE

(a) Measures shall be taken to avoid stresses at any temperature that are in excess of the maximum allowable stress applicable to that temperature. For example, the membrane stress at the maximum allowable working pressure at 150°F (65°C) shall never exceed the maximum allowable stress for 150°F (65°C). See ULT-27.

(b) Vessel use shall be restricted to fluids specifically considered for the design of the vessel. The physical characteristics of the contained fluid shall be such that a maximum operating temperature can be determined for the liquid phase at the maximum allowable working pressure of the vessel. The safety relief valve setting thus controls the maximum operating temperature of the vessel for the specific fluid.

(c) The allowable stress at 150°F (65°C) shall be used for the design of vessel parts that are exposed to the static head of cryogenic fluid but are not actually contacted by the fluid, such as, as in a dead-end cylinder connected to the bottom of a vessel that contains a gas cushion.

(d) Insulation shall be applied external to the pressure vessel.

ULT-5 GENERAL

(a) Materials covered by this Part subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table ULT-23. The allowable stress values of Table ULT-23 are limited to those materials which will be in contact with the cold liquid when subject to liquid head.

(b) Materials not covered by Part ULT may be used for vessel parts, provided such materials shall conform to one of the specifications in Section II and shall be limited to those materials permitted by another Part of Subsection C. The maximum allowable stress for such parts shall be determined at 150°F (65°C). All applicable requirements of that Part of Subsection C shall be met including any required impact tests.

(c) The 5%, 7%, 8%, and 9% nickel steels listed in Table ULT-23 shall be tested for notch ductility as required by UHT-5(d) and UHT-5(e) and UHT-6. These ductility tests shall be conducted at the lowest temperature at which pressure will be applied to the vessel or the minimum allowable temperature to be marked on the vessel, whichever is lower.

(d) For 5083 aluminum the provisions and requirements of UNF-65 for low temperature operation apply.

(e) For 5%, 7%, 8%, and 9% nickel steel vessels, all structural attachments and stiffening rings which are welded directly to pressure parts shall be made of materials of specified minimum strength equal to or greater than that of the material to which they are attached.

(f) The weldments of Types 304 and 316 stainless steels shall be Charpy impact tested as required by UG-84.8(a), except that the exemptions of UHA-51 do not apply. These impact tests shall be conducted at the lowest temperature at which pressure will be applied to the vessel or the minimum allowable temperature to be marked on the vessel, whichever is lower. The applicable minimum lateral expansion opposite the notch for all specimen sizes shall be as required in UHT-6(a)(3) and UHT-6(a)(4). All requirements of UHT-6(a)(3) and UHT-6(a)(4) shall apply.

(g) For Types 304 and 316 stainless steel vessels, all structural attachments and stiffening rings that are welded directly to pressure parts shall be made of either Type 304 or Type 316 stainless steel.

DESIGN

ULT-16 GENERAL

The rules in ULT-17 through ULT-57 apply specifically to the design of pressure vessels and vessel parts that are constructed of materials listed in Table ULT-23 and shall be used in conjunction with the requirements for *Design* in Subsection A and Subsection B, Part UW.

(a) The thermal stresses resulting from the differences between the base metal and the weld metal shall be considered in the design.

(b) For vessels made of 5%, 7%, 8%, and 9% nickel steels, the minimum thickness after forming of a section subject to pressure shall be $^3/_{16}$ in. (5 mm) and the maximum thickness of the base metal at welds shall be 2 in. (51 mm).

ULT-17 WELDED JOINTS

(a) All Category A, B, C, and D joints (see UW-3) shall be full penetration welds.

(b) The alignment of longitudinal joints in adjacent cylindrical sections or heads shall be displaced at least five times the thickness of the thicker material.

(c) In vessels of 5%, 7%, 8%, or 9% nickel steels, all Category D joints shall be in accordance with Figure UHT-18.1 or Figure UHT-18.2 when the nominal shell thickness at the opening exceeds 1 in. (25 mm).

(1) All joints of Category D attaching a nozzle neck to the vessel wall, and to a reinforcing pad if used, shall be full penetration groove weld conforming to Figure UHT-18.1 or Figure UHT-18.2 or any of the sketches in Figure UW-16.1 having full penetration welds.

(2) All joints of Category A shall be Type No. (1) of Table UW-12.

(3) All joints of Category B shall be Type No. (1) or (2) of Table UW-12.

(4) All joints of Category C shall be full penetration welds extending through the entire section at the joint.

(5) Joint alignment requirements of UHT-20 shall be met.

(d) Butt welds with one plate edge offset (see Figure UW-9-3) are prohibited anywhere in the vessel.

ULT-18 NOZZLES AND OTHER CONNECTIONS

(a) Nozzles shall not be located in Category A or B joints. When adjacent to Category A or B joints, the nearest edge of the nozzle-to-shell weld shall be at least five times the nominal thickness of the shell from the nearest edge of the Category A or B joint.

(b) The attachment of pipe and nozzle necks to vessel walls shall be by welded construction only.

ULT-23 MAXIMUM ALLOWABLE STRESS VALUES

Table ULT-23 gives the maximum allowable stress values at the temperatures indicated for materials conforming to the specifications listed therein. Values may be interpolated for intermediate temperatures (see UG-23).

ULT-27 THICKNESS OF SHELLS

The minimum thickness of any vessel part shall be the greater of the following:

(a) the thickness based on the MAWP at the top of the vessel in its normal operating position plus any other loadings per UG-22, including the static head of the most dense cryogenic liquid to be contained. The permissible stress value shall be determined for the applicable material in Table ULT-23 at the operating temperature corresponding to the saturation temperature at MAWP of the warmest cryogenic fluid contained. The maximum allowable compressive stress shall be determined in accordance with UG-23(b) at 150°F (65°C) and the requirements of UG-23(c) shall be met.

(b) the thickness determined by using the permissible stress value at 150°F (65°C) based on the MAWP at the top of the vessel in its normal operating position plus any other loadings per UG-22, except that no static head need be included.

ULT-28 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28 using the applicable figures in Section II, Part D, Subpart 3 at 150°F (65°C).

ULT-29 STIFFENING RINGS FOR SHELLS UNDER EXTERNAL PRESSURE

Rules covering the design of stiffening rings are given in UG-29. The design shall be based on the appropriate chart in Section II, Part D, Subpart 3 for the material used in the ring at 150°F (65°C).

ULT-30 STRUCTURAL ATTACHMENTS

(a) See ULT-5(e) for limitations on material used in permanent structural attachments in 5%, 7%, 8%, or 9% nickel steel vessels. See ULT-5(g) for limitations on material used in permanent structural attachments in Types 304 and 316 stainless steel vessels.

(b) The structural details of supporting lugs, rings, saddles, straps, and other types of supports shall be given special design consideration to minimize local stresses in attachment areas.

(c) Attachments to 5%, 7%, 8%, or 9% nickel steel vessels shall be made using a weld procedure qualified to Section IX.

(d) Attachments to Types 304 and 316 stainless steel vessels shall be made using a weld procedure meeting ULT-82.

Table ULT-23
V001 Maximum Allowable Stress Values in Tension for 5%, 7%, 8%, and 9% Nickel Steels; Types 304 and 316 Stainless Steels; and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

5% Nickel Steels, Customary Units
Plates: SA-645 Grade A [Note (1)]

Temperature [Note (2)], °F	Nonwelded Construction, ksi	Welded Construction [Note (3)], [Note (4)] UTS 100 ksi	Welded Construction [Note (3)], [Note (4)] UTS 95 ksi
−320	43.1	38.9	36.9
−300	39.4	37.9	36.1
−250	37.0	36.3	34.6
−200	36.0	35.0	33.3
−150	34.5	33.5	31.8
−100	32.9	32.1	30.5
−50	31.3	31.0	29.5
0	27.1	27.1	27.1
100	27.1	27.1	27.1
150	27.1	27.1	27.1

7% Nickel Steels, Customary Units
Plates: SA-553 Type III [Note (1)]

Temperature [Note (2)], °F	Nonwelded Construction, ksi	Welded Construction [Note (3)], [Note (4)] UTS 100 ksi	Welded Construction [Note (3)], [Note (4)] UTS 95 ksi
−320	41.9	38.9	36.9
−300	40.4	37.9	36.1
−250	37.5	36.3	34.6
−200	35.4	35.0	33.3
−150	33.8	33.5	31.8
−100	32.3	32.1	30.5
−50	31.0	31.0	29.5
−20 to 100	28.6	28.6	27.1
150	28.6	28.6	27.1

8% and 9% Nickel Steels, Customary Units
Plates: [Note (1)] SA-353, SA-553 Type I, and SA-553 Type II; Seamless Pipes and Tubes: SA-333 Grade 8 and SA-334 Grade 8; Forgings: SA-522

Temperature [Note (2)], °F	Nonwelded Construction, ksi	Welded Construction [Note (3)], [Note (4)] UTS 100 ksi	Welded Construction [Note (3)], [Note (4)] UTS 95 ksi
−320	43.9	38.9	36.9
−300	42.6	37.9	36.1
−250	39.8	36.3	34.6
−200	37.3	35.0	33.3
−150	35.1	33.5	31.8
−100	33.2	32.1	30.5
−50	31.6	31.0	29.5
0	28.6	28.6	27.1
100	28.6	28.6	27.1
150	28.6	28.6	27.1

Types 304 and 316 Stainless Steels, Customary Units

Spec. No.	Grade	Specified Minimum Strengths at Room Temperature: Tensile, ksi	Specified Minimum Strengths at Room Temperature: Yield, ksi	Maximum Allowable Stress, ksi, for Temperature [Note (2)], °F, Not Exceeding: −320	−300	−250	−200	−150	−100	−50	0	100	150
SA-240 nonwelded construction	304, 316	75.0	30.0	35.5	35.0	33.4	31.7	29.7	27.5	25.3	20.0	20.0	20.0
SA-240 welded construction	304, 316	75.0	30.0	23.6	23.4	23.1	22.8	22.4	22.1	21.8	20.0	20.0	20.0

Table ULT-23
V001 Maximum Allowable Stress Values in Tension for 5%, 7%, 8%, and 9% Nickel Steels; Types 304 and 316 Stainless Steels; and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction (Cont'd)

5083-0 Aluminum Alloy, Customary Units

Spec. No.	Alloy	Temper	Thickness, in.	Specified Minimum Strengths at Room Temperature		Maximum Allowable Stress, ksi, for Metal Temperature [Note (2)], °F, Not Exceeding									
				Tensile, ksi	Yield, ksi	−320	−300	−250	−200	−150	−100	−50	0	100	150
Sheet and Plate															
SB-209	5083	0	0.051–1.500	40	18	15.6	15.3	14.5	13.8	13.1	12.5	12.1	11.4	11.4	11.4
SB-209	5083	0	1.501–3.000	39	17	14.7	14.4	13.7	13.0	12.4	11.8	11.5	11.1	11.1	11.1
SB-209	5083	0	3.001–5.000	38	16	13.9	13.6	12.9	12.2	11.6	11.1	10.8	10.7	10.7	10.7
SB-209	5083	0	5.001–7.000	37	15	13.0	12.7	12.1	11.5	10.9	10.4	10.1	10.0	10.0	10.0
SB-209	5083	0	7.001–8.000	36	14	12.1	11.9	11.3	10.7	10.2	9.7	9.4	9.3	9.3	9.3
Rods, Bars, and Shapes															
SB-221	5083	0	Up through 5.000	39	16	13.9	13.6	12.9	12.2	11.6	11.1	10.8	10.7	10.7	10.7
Seamless Extruded Tube															
SB-241	5083	0	Up through 5.000	39	16	13.9	13.6	12.9	12.2	11.6	11.1	10.8	10.7	10.7	10.7

Table ULT-23
V001 Maximum Allowable Stress Values in Tension for 5%, 7%, 8%, and 9% Nickel Steels; Types 304 and 316 Stainless Steels; and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction (Cont'd)

5% Nickel Steels, SI Units
Plates: SA-645 [Note (1)]

Temperature [Note (2)], °C	Nonwelded Construction, MPa	Welded Construction [Note (3)], [Note (4)] UTS 690 MPa	Welded Construction [Note (3)], [Note (4)] UTS 655 MPa
−195	296	268	254
−170	257	255	243
−145	253	247	235
−120	245	238	226
−95	235	229	217
−70	226	221	210
−45	215	213	203
−20	187	187	187
40	187	187	187
65	187	187	187

7% Nickel Steels, SI Units
Plates: SA-553 Type III [Note (1)]

Temperature [Note (2)], °C	Nonwelded Construction, MPa	Welded Construction [Note (3)], [Note (4)] UTS 690 MPa	Welded Construction [Note (3)], [Note (4)] UTS 655 MPa
−195	289	268	254
−170	267	255	243
−145	252	247	235
−120	240	238	226
−95	231	229	217
−70	222	220	210
−45	214	214	203
−30 to 40	197	197	187
65	197	197	187

8% and 9% Nickel Steels, SI Units
Plates: SA-353, SA-553 Type I, and SA-553 Type II; Seamless Pipes and Tubes: SA-333 Grade 8 and SA-334 Grade 8; Forgings: SA-522 [Note (1)]

Temperature [Note (2)], °C	Nonwelded Construction, MPa	Welded Construction [Note (3)], [Note (4)] UTS 690 MPa	Welded Construction [Note (3)], [Note (4)] UTS 655 MPa
−195	302	268	254
−170	283	255	243
−145	267	247	235
−120	252	238	226
−95	239	229	217
−70	228	220	210
−45	218	214	203
−40	197	197	187
40	197	197	187
65	197	197	187

Types 304 and 316 Stainless Steels, SI Units

Spec. No.	Grade	Specified Minimum Strengths at Room Temperature: Tensile, MPa	Yield, MPa	Maximum Allowable Stress, MPa, for Temperature [Note (2)], °C, Not Exceeding: −195	−170	−145	−120	−95	−70	−45	−20	40	65
SA-240 nonwelded construction	304, 316	515	205	243	234	223	212	199	187	173	137	137	137
SA-240 welded construction	304, 316	515	205	161	159	157	155	153	151	149	137	137	137

Table ULT-23
V001 Maximum Allowable Stress Values in Tension for 5%, 7%, 8%, and 9% Nickel Steels; Types 304 and 316 Stainless Steels; and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction (Cont'd)

5083-0 Aluminum Alloy, SI Units

Spec. No.	Alloy	Temper	Thickness, mm	Specified Minimum Strengths at Room Temperature: Tensile, MPa	Yield, MPa	Maximum Allowable Stress, MPa, for Metal Temperature [Note (2)], °C, Not Exceeding: −195	−170	−145	−120	−95	−70	−45	−20	40	65
Sheet and Plate															
SB-209	5083	0	1.30–38.10	276	124	107	103	97.9	93.6	89.3	85.8	83.4	78.8	78.8	78.8
SB-209	5083	0	38.13–76.20	269	117	101	96.8	92.4	88.3	84.5	81.0	79.3	76.8	76.8	76.8
SB-209	5083	0	76.23–127.00	262	110	95.7	91.2	86.9	82.7	79.1	76.2	74.4	73.5	73.5	73.5
SB-209	5083	0	127.03–177.80	255	103	89.5	85.3	81.7	77.9	74.3	71.4	69.6	69.0	69.0	69.0
SB-209	5083	0	199.83–203.20	248	97	83.4	80.0	76.1	72.6	69.5	66.5	64.8	64.4	64.4	64.4
Rods, Bars, and Shapes															
SB-221	5083	0	Up through 127.00	269	110	95.7	91.2	86.9	82.7	79.1	76.2	74.4	73.5	73.5	73.5
Seamless Extruded Tube															
SB-241	5083	0	Up through 127.00	269	110	95.7	91.2	86.9	82.7	79.1	76.2	74.4	73.5	73.5	73.5

NOTES:
(1) Minimum thickness after forming any section subject to pressure shall be $^3/_{16}$ in. (5 mm), and maximum thickness of the base metal at welds shall be 2 in. (51 mm).
(2) Stress values at intermediate temperatures may be interpolated.
(3) The minimum tensile strength of the reduced tension specimen in accordance with Section IX, Figures QW-462.1(a) through QW-462.1(e) shall not be less than 100 ksi (690 MPa) or 95 ksi (655 MPa), respectively, at room temperature. Choice of UTS depends on welding process and filler metal used in the construction.
(4) Welded construction allowable stresses apply only to butt joints.

ULT-56 POSTWELD HEAT TREATMENT

(a) For 5%, 7%, 8%, or 9% nickel steels, the provisions of UHT-56, UHT-80, and UHT-81 apply.

(b) For 5083 aluminum, the provisions of UNF-56 apply.

(c) For Types 304 and 316 stainless steel vessels, the provisions of UHA-32 apply.

ULT-57 EXAMINATION

(a) All butt joints shall be examined by 100% radiography.

(b) All attachment welds, and all welded joints subject to pressure not examined by radiography or ultrasonic testing, shall be given a liquid penetrant examination either before or after hydrotest. Relevant indications are those which result from imperfections. Any relevant linear indication greater than $^1/_{16}$ in. (1.6 mm) shall be repaired or removed.

When a pneumatic test is conducted in accordance with ULT-100, these liquid penetrant examinations shall be performed prior to the pneumatic test.

(c) For 5083 aluminum, the requirements of UNF-91 apply.

FABRICATION

ULT-75 GENERAL

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed to this Part and shall be used in conjunction with the requirements for *Fabrication* in Subsection A and Part UW of Subsection B.

ULT-79 FORMING SHELL SECTIONS AND HEADS

The requirements and limitations of UNF-77 apply for 5083 aluminum, and of UHT-79 for 5%, 7%, 8%, or 9% nickel steel.

ULT-82 WELDING

(a) A separate welding procedure qualification shall be made, as prescribed in Section IX, Part QW, except that the procedure qualification tests on tension specimens conforming to Section IX, Figures QW-462.1(a) through

QW-462.1(e) and prescribed in Section IX, Tables QW-451.1 through QW-451.4 shall be four in number, two of which when tested at room temperature shall meet the minimum tensile strength requirements for room temperature as listed in Table ULT-82 and two of which when tested at or below the vessel minimum allowable temperature shall meet the minimum tensile strength requirements for that test temperature as listed in the applicable table, except that the requirements for the two tests at vessel minimum allowable temperature shall not be applied to procedure qualification for 5083 aluminum welded with 5183 aluminum filler metal.

(b) For 5%, 7%, 8%, or 9% nickel steels, the provisions of UHT-82, UHT-83, UHT-84, and UHT-85 apply.

(c) For Types 304 and 316 stainless steel vessels, the provisions of UHA-51 apply.

ULT-86 MARKING ON PLATE AND OTHER MATERIALS (25)

For 5%, 7%, 8%, or 9% nickel steel the requirements of UHT-86 apply. For the use of other markings in lieu of stamping, see UG-77.1(b).

INSPECTION AND TESTS

ULT-90 GENERAL

The provisions for inspection and testing in Subsections A and B shall apply to vessels and vessel parts constructed of materials covered by this Part, except as modified herein.

Table ULT-82
Minimum Tensile Strength Requirements for Welding Procedure Qualification Tests on Tension Specimens Conforming to Section IX, Figures QW-462.1(a) Through QW-462.1(e)

Temp. [Note (1)], °F	SA-645, Customary Units — Welded Construction — UTS 100 ksi	SA-645, Customary Units — Welded Construction — UTS 95 ksi	SA-353; SA-553 Types I, II, and III; SA-333 Grade 8; SA-334; SA-522, Customary Units — Welded Construction — UTS 100 ksi	SA-353; SA-553 Types I, II, and III; SA-333 Grade 8; SA-334; SA-522, Customary Units — Welded Construction — UTS 95 ksi
−320	136	129	136	129
−300	133	126	133	126
−250	125	121	125	121
−200	122	116	122	116
−150	117	111	117	111
−100	112	107	112	107
−50	108	103	108	103
0	95	95	100	95
100	95	95	100	95
150	95	95	100	95

5083-0 Aluminum Alloy, Customary Units

Spec. No.	Nominal Thickness, in.	Minimum Tensile Strength, ksi, for Metal Temperature [Note (1)], °F, Not Exceeding −320	−300	−250	−200	−150	−100	−50	0	100	150
Sheet and Plate											
SB-209	0.051 ≤ t < 1.50	55.2	53.3	48.2	43.8	41.4	40.4	40	40	40	40
	1.50 ≤ t < 3.00	53.8	52	47	42.7	40.4	39.4	39.1	39	39	39
	3.00 ≤ t < 5.00	52.5	50.7	45.8	41.6	39.4	38.4	38.1	38	38	38
	5.00 ≤ t < 7.00	51.1	49.3	44.6	40.5	38.3	37.4	37.1	37	37	37
	7.00 ≤ t < 8.00	49.7	48	43.4	39.4	37.3	36.4	36.1	36	36	36
Rods, Bars, and Shapes											
SB-221	1 ≤ 5.00	53.8	52	47	42.7	40.4	39.4	39.1	39	39	39
Seamless Extruded Tube											
SB-241	t ≤ 5.00	53.8	52	47	42.7	40.4	39.4	39.1	39	39	39

Types 304 and 316 Stainless Steels, Customary Units

Spec. No.	Minimum Tensile Strength, ksi, for Metal Temperature [Note (1)], °F, Not Exceeding −320	−300	−250	−200	−150	−100	−50	0	100	150
SA-240	82.7	82.1	80.9	79.7	78.5	77.4	76.2	75.0	75.0	75.0

NOTE:
(1) Strength values at intermediate temperatures may be interpolated.

Table ULT-82M
Minimum Tensile Strength Requirements for Welding Procedure Qualification Tests on Tension Specimens Conforming to Section IX, Figures QW-462.1(a) Through QW-462.1(e)

Temp. [Note (1)], °C	SA-645, SI Units		SA-353; SA-553 Types I, II, and III; SA-333 Grade 8; SA-334; SA-522, SI Units	
	Welded Construction		Welded Construction	
	UTS 689 MPa	UTS 655 MPa	UTS 689 MPa	UTS 655 MPa
−196	938	889	938	889
−184	917	869	917	869
−156	862	834	862	834
−129	841	800	841	800
−101	807	765	807	765
−73	772	738	772	738
−46	745	710	745	710
−18	655	655	689	655
38	655	655	689	655
65	655	655	689	655

5083-O Aluminum Alloy, SI Units

Spec. No.	Nominal Thickness, mm	Minimum Tensile Strength, MPa, for Metal Temperature [Note (1)], °C, Not Exceeding									
		−196	−184	−156	−129	−101	−73	−46	−18	38	65
Sheet and Plate											
SB-209	1.30 ≤ t < 38.1	381	368	332	302	285	279	276	276	276	276
	38.1 ≤ t < 76.2	371	359	324	294	279	272	270	269	269	269
	76.2 ≤ t < 127	362	350	316	287	272	265	263	262	262	262
	127 ≤ t < 177.8	352	340	308	279	264	258	256	255	255	255
	177.8 ≤ t ≤ 203.2	343	331	299	272	257	251	249	248	248	248
Rods, Bars, and Shapes											
SB-221	t ≤ 127	371	358	324	294	279	272	270	269	269	269
Seamless Extruded Tube											
SB-241	t ≤ 127	371	358	324	294	279	272	270	269	269	269

Types 304 and 316 Stainless Steels, SI Units

Spec. No.	Minimum Tensile Strength, MPa, for Metal Temperature [Note (1)], °C, Not Exceeding									
	−196	−184	−156	−129	−101	−73	−46	−18	38	65
SA-240	570	566	558	550	541	534	525	517	517	517

NOTE:
(1) Strength values at intermediate temperatures may be interpolated.

ULT-99 HYDROSTATIC TEST

The vessel shall be hydrostatically pressure tested at ambient temperature in the operating position for a minimum of 15 min, using the following requirements of (a) or (b), whichever is applicable:

(a) Except for vessels covered by (b) below, a hydrostatic test shall be performed in accordance with UG-99, except that the ratio of stresses is not applied, and the test pressure shall be at least 1.4 times the design pressure at 150°F (65°C).

(b) When the test procedure in (a) above will cause a nominal membrane stress greater than 95% of specified minimum yield strength or 50% of specified minimum tensile strength of the material in any part of the vessel, the hydrostatic test may be conducted at a pressure that limits the nominal membrane stress at such part to the lesser of those values. When these conditions limit the hydrostatic test pressure to a value less than 110% of the maximum allowable working pressure at 100°F (38°C), a pneumatic test in accordance with ULT-100 shall also be conducted.

(c) Vessels that are to be installed in the vertical position may be tested in the horizontal position, provided all components of the vessel are hydrostatically tested for a minimum of 15 min at a pressure not less than 1.4 times the design pressure at 150°F (65°C) plus the equivalent of the head of the test liquid in the operating position.

ULT-100 PNEUMATIC TEST

(a) A pneumatic test prescribed in this paragraph may be used in lieu of the hydrostatic test prescribed in ULT-99 for vessels that are either:

(1) so designed and/or supported that they cannot safely be filled with water, or

(2) are not readily dried, and will be used in services where traces of testing liquid cannot be tolerated.

(b) The vessel shall be tested at ambient temperature for a minimum of 15 min.

(c) The pneumatic test shall be performed in accordance with UG-100, except that the ratio of stresses is not applied, and the test pressure shall be at least 1.2 times the internal pressure at 150°F (65°C). In no case shall the pneumatic test pressure exceed 1.2 times the basis for calculated test pressure as defined in Mandatory Appendix 3, 3-2.

MARKING AND REPORTS

ULT-115 GENERAL

The provisions for marking and reports in UG-115 through UG-120 shall apply to vessels constructed to this Part, with the following supplements to the marking and Manufacturer's Data Reports:

(a) The vessel markings shall be in accordance with UG-116 except:

(1) the letters ULT shall be applied below the Certification Mark and Designator;

(2) the following markings shall be used instead of those in UG-116(a)(3) and UG-116(a)(4):

Maximum Allowable Working Pressure: ___ psi at 150°F
Minimum Allowable Temperature: Minus ___F

Service Restricted to the Following	Operating Temperature
Liquid ______	Minus ___ F
Liquid ______	Minus ___ F
Liquid ______	Minus ___ F
Liquid ______	Minus ___ F

GENERAL NOTES:

(a) Minimum allowable temperature is the temperature of the coldest cryogenic liquid which will be admitted to or stored within the vessel.

(b) Operating temperature for the cryogenic liquid is its saturation temperature at MAWP. All liquids that may be contained in the vessel shall be listed.

(b) On the Manufacturer's Data Report, under "Remarks", show the additional marking notations from (a) above.

(c) Unless the requirements of (1) and (2) below are met, for 5%, 8%, and 9% nickel steels, the use of nameplates is mandatory for shell thicknesses below $^1/_2$ in. (13 mm); nameplates are preferred in all thicknesses.

(1) The materials shall be limited to aluminum as follows: SB-209 Alloys 3003, 5083, 5454, and 6061; SB-241 Alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 Alloys 3003, 5083, and 6061.

(2) The minimum nominal plate thickness shall be 0.249 in. (6.32 mm), or the minimum nominal pipe thickness shall be 0.133 in. (3.38 mm).

OVERPRESSURE PROTECTION

ULT-125 GENERAL

The provisions for overpressure protection in this Division shall apply to vessels constructed to this Part with the additional requirement that the safety relief device be suitable for low temperature service and installed to remain at ambient temperature except when relieving.

(25)

SUBSECTION D
REQUIREMENTS FOR SPECIFIC TYPES OF PRESSURE VESSELS AND COMPONENTS

(25)

PART UAS
VESSELS WITH ACRYLIC CYLINDRICAL SHELLS

UAS-1 SCOPE AND SERVICE RESTRICTION

(a) The metallic components of a vessel containing cast acrylic shells shall meet the requirements of ASME Section VIII, Division 1.

(b) This Part requires the use of ASME PVHO-1 for the acrylic parts. When requirements from ASME PVHO are referenced, the terminology from ASME PVHO-1 is used.

(c) The acrylic shell section of pressure vessels constructed to this Part shall be cylindrical acrylic windows constructed to the requirements of ASME PVHO-1 and the requirements of this Part.

(d) Vessels designed and constructed to the requirements of this Part shall be limited to the following service and design restrictions for both the acrylic shells and all metallic components:

(1) The maximum internal design pressure shall be equal to the MAWP.

(2) The maximum external design pressure shall not exceed 15 psi (100 kPa).

(3) The maximum allowable working pressure (MAWP) shall not exceed 150 psi (1 MPa).

(4) The maximum design temperature shall not be hotter than 125°F (52°C).

(5) The minimum design temperature shall not be colder than 0°F (−18°C).

(6) The fluids contained in the vessel shall be nonlethal and compatible with acrylic and metallic parts per UG-4(f). Liquids shall be at temperatures below their boiling point.

(7) The number of pressure cycles to the design pressure shall not exceed 10,000 for internally or externally pressurized vessels. Pressurizations to less than the design pressure shall be counted as a fraction of the cycle (i.e., pressurization to half of the design pressure shall be counted as half of a cycle).

(8) The pressurization and depressurization rates shall be less than 150 psi/sec (1 MPa/s).

(9) The design life of the acrylic window shall be 10 yr from the date of fabrication as noted in the data report.

UAS-2 MATERIALS

(a) The acrylic window shall be manufactured from cast polymethyl methacrylate referred to as acrylic.

(b) Metallic materials subject to stress, due to pressure application, shall conform to the requirements of Section VIII, Division 1.

(c) The acrylic material used to manufacture the cylindrical shell for the pressure vessel shall meet the requirements in ASME PVHO-1, Section 2-3.

(d) Acrylic windows exposed to sunlight shall have UV inhibitors added to the external surface.

UAS-3 DESIGN

(a) The design of all metallic components subject to stress, due to pressure, shall conform to the requirements of Section VIII Division 1.

(b) The minimum required thickness of the acrylic window shall be determined using the requirements in ASME PVHO-1, Section 2-2 with the following restrictions:

(1) The allowable window configuration is limited to cylindrical windows, ASME PVHO-1, Figure 2-2.2.1-3(b).

(2) The short-term critical pressure (STCP) shall be determined by a calculation using ASME PVHO-1, paras. 2-2.2.2 and 2-2.5.1. Determination of the STCP by testing, as defined in ASME PVHO-1, para. 2-2.2.3, is not allowed by this Part.

(3) The acrylic window section of the vessel shall be a seamless cast cylinder with flat end bearing surfaces. The detail for the cylindrical window is shown in ASME PVHO-1, Figure 2-2.11.10-2, illustration (c).

(4) The minimum wall thickness of any cast cylindrical acrylic window shall be no less than $^1/_2$ in. (12.5 mm).

(5) No through or blind holes or openings are permitted in the wall of the acrylic window.

(6) Threaded connections in or on the acrylic window are not permitted.

(7) The joint between the acrylic window and the metallic section shall meet the requirements in ASME PVHO-1, para. 2.2.10 and Figure 2-2.10.1-5.

(8) The compression of the elastomeric gasket used to seal the acrylic window to the metallic components shall meet the requirements in ASME PVHO-1, para. 2-2.11.

UAS-4 FABRICATION

(a) The fabrication of all metallic components subject to stress, due to pressure, shall conform to the requirements of Section VIII, Division 1.

(b) The fabrication of the acrylic window shall conform to the requirements of ASME PVHO-1, Section 2-4.

UAS-5 INSPECTION

(a) Inspection of all metallic components subject to stress, due to pressure, shall conform to the requirements of Section VIII, Division 1.

(b) Inspection of the acrylic window shall conform to the requirements of ASME PVHO-1, Section 2-5.

UAS-6 TESTING

Vessels manufactured in accordance with this Part will be subject to a hydrostatic test in accordance with the requirements of UG-99 and ASME PVHO-1, para. 2-7.8. The ASME Section VIII Certificate Holder shall be responsible for completing ASME PVHO-1, Form VP-5 and including it with the acrylic window certification following the UG-99 hydrostatic test.

UAS-7 MARKING

(a) The completed vessel shall be marked to the requirements of Section VIII, Division 1.

(b) The acrylic window manufacturer shall mark the acrylic window to the requirements of ASME PVHO-1, Section 2-6.

(c) The nameplate shall be attached to a permanent metallic part of the pressure vessel.

(d) The type of construction shall be indicated directly below the Certification Mark and U Designator by applying the letter "A."

UAS-8 ACRYLIC WINDOW MANUFACTURER CERTIFICATION

(a) The acrylic window manufacturer shall provide a certification that the acrylic window has been constructed in accordance with all applicable requirements of this Part. ASME PVHO-1, Form VP-1 shall be used to document certification.

(b) A design certification for each acrylic window, all pertinent design data, and any additional information used in the design shall be referenced on the certification. ASME PVHO-1, Form VP-2 shall be used to document certification.

(c) The material manufacturer shall provide certification that the acrylic used to manufacture the acrylic window meets or exceeds the minimum values of physical properties specified in ASME PVHO-1, Table 2-3.4-1. ASME PVHO-1, Form VP-3 shall be used to document certification.

(d) The acrylic window manufacturer shall provide a certification that the acrylic window material meets the minimum values specified in ASME PVHO-1, Table 2-3.4-2 and that these properties have been experimentally verified. ASME PVHO-1, Form VP-4 shall be used to document certification.

UAS-9 ACRYLIC VESSELS MAINTENANCE AND OPERATION

The Manufacturer shall furnish to the user or the user's designated agent the following documentation:

(a) instructions critical to the maintenance of the vessel

(b) instructions critical to the operation of the vessel

(25)

PART UCC
DESIGN RULES FOR CLAMP CONNECTIONS

UCC-1 SCOPE

(a) The rules in this Part apply specifically to the design of clamp connections for pressure vessels and vessel parts and shall be used in conjunction with the applicable requirements in Subsections A, B, C, and D of this Division. These rules shall not be used for the determination of thickness of tubesheets integral with a hub nor for the determination of thickness of covers. These rules provide only for hydrostatic end loads, assembly, and gasket seating. Consideration shall be given to loads other than pressure, such as piping loads, that may act on the clamp connection (see UG-22).

(b) The design of a clamp connection involves the selection of the gasket, bolting, hub, and clamp geometry. Bolting shall be selected to satisfy the requirements of UCC-4. Connection dimensions shall be such that the stresses in the clamp and the hub, calculated in accordance with UCC-6 and UCC-7, do not exceed the allowable stresses specified in Table UCC-8. All calculations shall be made on dimensions in the corroded condition. Calculations for assembly, gasket seating, and operating conditions are required.

(c) It is recommended that either a pressure energized and/or low seating load gasket be used to compensate for possible nonuniformity in the gasket seating force distribution. Hub faces shall be designed such as to have metal-to-metal contact outside the gasket seal diameter. This may be provided by recessing the hub faces or by use of a metal spacer (see Figure UCC-1). The contact area shall be sufficient to prevent yielding of either the hub face or spacer under both operating and assembly loads.

(d) It is recognized that there are clamp designs that utilize no wedging action during assembly since clamping surfaces are parallel to the hub faces. Such designs are acceptable and shall satisfy the bolting and corresponding clamp and hub requirements of a clamp connection designed for a total included clamping angle of 10 deg.

(e) The design method used herein to calculate stresses, loads, and moments may also be used in designing clamp connections of shapes differing from those shown in Figures UCC-1 and UCC-2, and for clamps consisting of more than two circumferential segments. The design formulas used herein may be modified when designing clamp connections of shape differing from those shown in Figures UCC-1 and UCC-2, provided that the basis for the modifications is in accordance with U-2(g). However, the requirements of (f) below shall be complied with for all clamp connections.

(f) Clamps designed to the rules of this Part shall be provided with a bolt retainer. The retainer shall be designed to hold the clamps together independently in the operating condition in case of failure of the primary bolting. Clamp hub friction shall not be considered as a retainer method. Multiple bolting (two or more bolts per lug) is an acceptable alternative for meeting this requirement.

UCC-2 MATERIALS

(a) Materials used in the construction of clamp connections shall comply with the requirements given in UG-5 through UG-14.

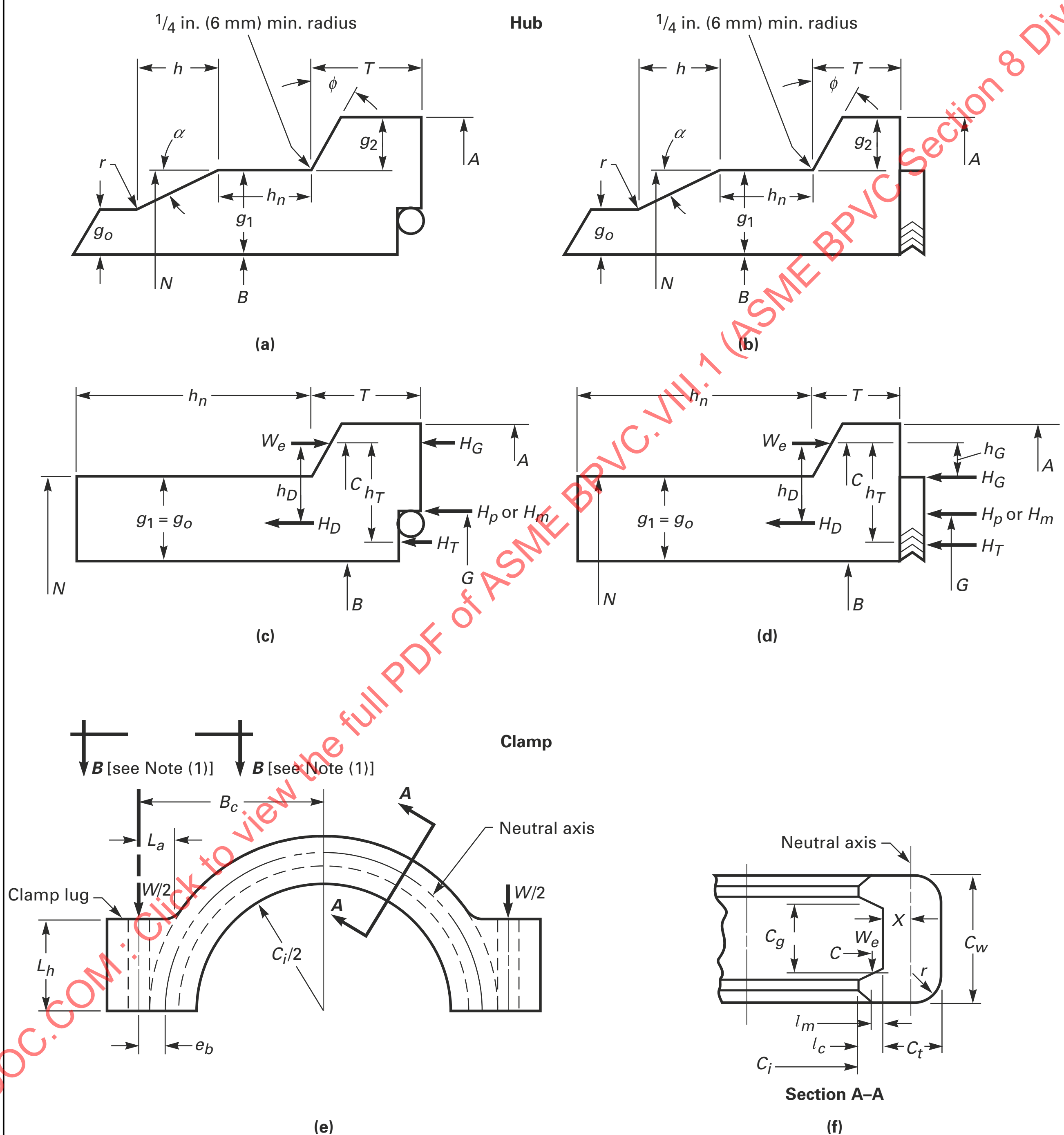
(b) Hubs made from ferritic steel and designed in accordance with the rules herein shall be given a normalizing or full-annealing heat treatment when the thickness of the hub neck section exceeds 3 in. (75 mm).

(c) Cast steel hubs and clamps shall be examined and repaired in accordance with Mandatory Appendix 7.

(d) Hubs and clamps shall not be machined from plate.

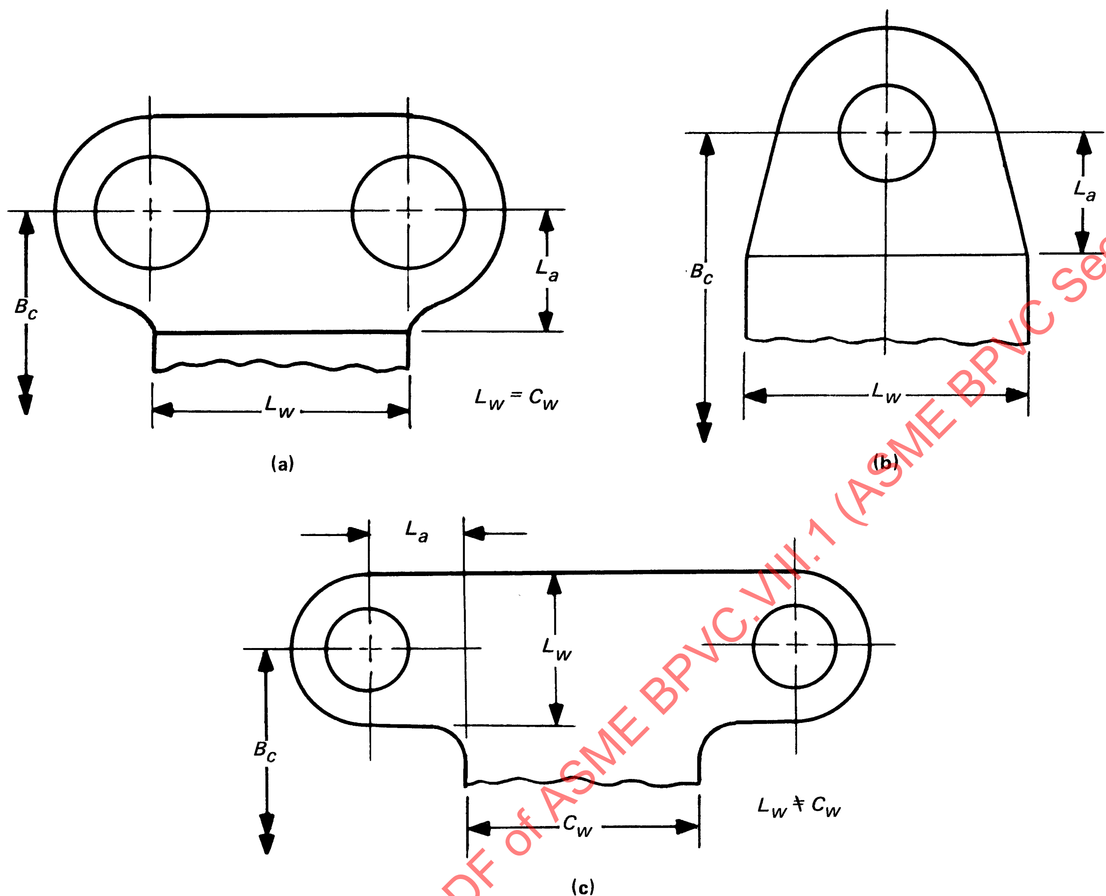
(e) Bolts and studs shall comply with UG-12. Minimum diameter shall be $^1/_2$ in. (13 mm). Nuts and washers shall comply with UG-13.

Figure UCC-1
Typical Hub and Clamp



NOTE:
(1) See Figure UCC-2 for Section B-B.

Figure UCC-2
Typical Clamp Lug Configurations



GENERAL NOTE: See UCC-1(f) for retainer requirements.

UCC-3 NOTATION

The notation below is used in the formulas for the design of clamp-type connections (see also Figures UCC-1 and UCC-2).

A = outside diameter of hub
A_1 = partial clamp area
= $(C_w - 2C_t)C_t$
A_2 = partial clamp area
= $1.571C_t^2$
A_3 = partial clamp area
= $(C_w - C_g)l_c$
A_{bL} = total cross-sectional area of the bolts per clamp lug using the smaller of the root diameter of the thread or least diameter of unthreaded portion. Cross-sectional area of bolt retainer shall not be included in calculation of this area. When multiple bolting is used in lieu of bolt retainer, the total cross-sectional area of all the bolts per clamp lug shall be used.
A_c = total effective clamp cross-sectional area
= $A_1 + A_2 + A_3$
A_{m1} = total cross-sectional area of bolts per clamp lug at root of thread or section of least diameter under stress, required for the operating conditions
= $W_{m1}/2S_b$
A_{m2} = total cross-sectional area of bolts per clamp lug at root of thread or section of least diameter under stress, required for gasket seating
= $W_{m2}/2S_a$
A_{m3} = total cross-sectional area of bolts per clamp lug at root of thread or section of least diameter under stress, required for assembly conditions
= $W_{m3}/2S_a$
A_{mL} = total required cross-sectional area of bolts per clamp lug taken as the greater of A_{m1}, A_{m2}, or A_{m3}
B = inside diameter of hub
b = effective gasket or joint-contact-surface seating width [see Note in Mandatory Appendix 2, 2-5(c)(1)]

B_c = radial distance from connection centerline to center of bolts [see Figure UCC-1, sketch (e)]

b_o = basic gasket or joint-contact-surface seating width (see Mandatory Appendix 2, Table 2-5.2)

C = diameter of effective clamp-hub reaction circle
= $(A + C_i)/2$

C_g = effective clamp gap determined at diameter C

C_i = inside diameter of clamp

C_t = effective clamp thickness (C_t shall be equal to or greater than r)

C_w = clamp width

e_b = radial distance from center of the bolts to the centroid of the clamp cross section
= $B_c - (C_i/2) - l_c - X$

f = hub stress correction factor from Mandatory Appendix 2, Table 2-5.2. (This is the ratio of the stress in the small end of the hub to the stress in the large end.) (For values below limit of the figure, use f = 1.0.)

G = diameter at location of gasket load reaction. Except as noted in Figure UCC-1, G is defined as follows (see Mandatory Appendix 2, Table 2-5.2):

(a) when $b_o \leq {}^1\!/_4$ in. (6 mm), G = mean diameter of gasket or joint contact face;

(b) when $b_o > {}^1\!/_4$ in. (6 mm), G = outside diameter of gasket contact face less $2b$

g_1 = thickness of hub neck at intersection with hub shoulder

g_2 = height of hub shoulder (g_2 shall not be larger than T.)

g_o = thickness of hub neck at small end

$\bar{g}$ = radial distance from the hub inside diameter B to the hub shoulder ring centroid

$$= \frac{T{g_1}^2 + h_2 g_2 (2g_1 + g_2)}{2(Tg_1 + h_2 g_2)}$$

H = total hydrostatic end force
= $0.785G^2P$

h = hub taper length

h_2 = average thickness of hub shoulder
= $T - (g_2 \tan \phi)/2$

H_D = hydrostatic end force on bore area
= $0.785B^2P$

h_D = radial distance from effective clamp-hub reaction circle to the circle on which H_D acts
= $[C - (B + g_1)]/2$

H_G = difference between total effective axial clamping preload and the sum of total hydrostatic end force and total joint contact surface compression
= $[1.571\ W/\tan(\phi + \mu)] - (H + H_p)$

h_G = radial distance from effective clamp-hub reaction circle to the circle on which H_G acts in. (mm) (for full face contact geometries, h_G = 0)

H_m = total axial gasket seating requirements for make-up ($3.14bGy$ or the axial seating load for self-energizing gaskets, if significant)

h_n = hub neck length [minimum length of h_n is $0.5g_1$ or ${}^1\!/_4$ in. (6 mm), whichever is larger]

h_o = $\sqrt{Bg_o}$

H_p = total joint contact surface compression load
= $2b \times 3.14GmP$
= (For self-energized gaskets, use H_p = 0 or actual retaining load if significant.)

H_T = difference between total hydrostatic end force and hydrostatic end force on bore area
= $H - H_D$

h_T = radial distance from effective clamp-hub reaction circle to the circle on which H_T acts
= $[C - (B + G)/2]/2$

$\bar{h}$ = axial distance from the hub face to the hub shoulder ring centroid

$$= \frac{T^2 g_1 + {h_2}^2 g_2}{2(Tg_1 + h_2 g_2)}$$

I_c = moment of inertia of clamp relative to neutral axis of entire section

$$= \left(\frac{A_1}{3} + \frac{A_2}{4}\right)C_t^2 + \frac{A_3 {l_c}^2}{3} - A_c X^2$$

I_h = moment of inertia of hub shoulder relative to its neutral axis

$$= \frac{g_1 T^3}{3} + \frac{g_2 {h_2}^3}{3} - (g_2 h_2 + g_1 T)\bar{h}^2$$

L_a = distance from W to the point where the clamp lug joins the clamp body [see Figure UCC-1, sketch (e)]

l_c = effective clamp lip length

L_h = clamp lug height [see Figure UCC-1, sketch (e)]

l_m = effective clamp lip moment arm
= $l_c - (C - C_i)/2$

L_w = clamp lug width (see Figure UCC-2)

m = gasket factor from Mandatary Appendix 2, Table 2-5.1

M_D = moment due to H_D
= $H_D h_D$

M_F = offset moment
= $H_D\ (g_1 - g_o)/2$

M_G = moment due to H_G
= $H_G\ h_G$

M_H = reaction moment at hub neck

$$= M_o \Big/ \left\{ 1 + \frac{1.818}{\sqrt{Bg_1}} \times \left[T - \bar{h} + \frac{3.305 I_h}{{g_1}^2 (B/2 + \bar{g})} \right] \right\}$$

M_o = total rotational moment on hub (see UCC-5)

M_P = pressure moment
= $3.14 \times PBT\ (T/2 - \bar{h})$

M_R = radial clamp equilibriating moment
= $1.571\ W\ \{\bar{h} - T + [(C - N)\tan\phi]/2\}$

M_T = moment due to H_T
= $H_T h_T$

N = outside diameter of hub neck

P = internal design pressure (see UG-21)

Q = reaction shear force at hub neck
= $1.818 M_H / \sqrt{B g_1}$

r = clamp or hub cross section corner radius
= $^1/_4$ in. (6 mm) min., C_t max.

S_1 = hub longitudinal stress on outside at hub neck

S_2 = maximum Lamé hoop stress at bore of hub

S_3 = maximum hub shear stress at shoulder

S_4 = maximum radial hub shear stress in neck

S_5 = clamp longitudinal stress at clamp body inner diameter

S_6 = clamp tangential stress at clamp body outer diameter

S_7 = maximum shear stress in clamp lips

S_8 = clamp lug bending stress

S_9 = effective bearing stress between clamp and hub

S_a = allowable bolt stress at room temperature

S_{AC} = allowable design stress for clamp material at (assembly condition) room temperature

S_{AH} = allowable design stress for hub material at (assembly condition) room temperature

S_b = allowable bolt stress at design temperature

S_{OC} = allowable design stress for clamp material at (operating condition) design temperature

S_{OH} = allowable design stress for hub material at (operating condition) design temperature

T = thickness of hub shoulder per Figure UCC-1

W = total design bolt load required for operating or assembly conditions, as applicable

W_e = total effective axial clamping preload on one clamp lip and hub shoulder (gasket seating or assembly)
= $1.571\ W / \tan(\phi + \mu)$

W_{m1} = minimum required total bolt load for the operating conditions [see UCC-4(b)(1)]

W_{m2} = minimum required total bolt load for gasket seating [see UCC-4(b)(2)]

W_{m3} = minimum required total bolt load for assembly [see UCC-4(b)(3)]

X = clamp dimension to neutral axis per Figure UCC-1, sketch (f)
= $\left[\left(\frac{C_w}{2} - \frac{C_t}{3}\right)C_t^2 - \frac{(C_w - C_g)}{2} l_c^{\,2}\right] / A_c$

y = gasket seating stress (from Mandatory Appendix 2, Table 2-5.1)

Z = clamp-hub taper angle, deg (for gasket seating and preload, $Z = \phi + \mu$; for operating, $Z = \phi - \mu$) [see UCC-4(b)(4)]

α = hub transition angle, deg
= 45 deg max.

μ = friction angle, deg

ϕ = clamp shoulder angle, deg
= 40 deg max.

UCC-4 BOLT LOADS

(a) General. During assembly of the clamp connection, the design bolt load W is resolved into an effective clamp preload W_e, which is a function of the clamp-hub taper angle ϕ and the friction angle μ. An appropriate friction angle shall be established by the Manufacturer, based on test results for both assembly and operating conditions.

(b) Calculations. In the design of bolting for a clamp connection, complete calculations shall be made for three separate and independent sets of conditions that are defined as follows:

(1) The required bolt load for the operating conditions W_{m1} shall be sufficient to resist the hydrostatic end force H exerted by the design pressure acting on the area bounded by the diameter of gasket reaction plus a gasket compressive load H_p, which experience has shown to be sufficient to ensure a tight joint. The minimum operating bolt load W_{m1} shall be determined in accordance with eq. (1):

$$W_{m1} = 0.637\left(H + H_p\right)\tan\left(\phi - \mu\right) \tag{1}$$

(2) Before a tight joint can be obtained, it is necessary to seat the gasket or joint-contact surface properly by applying a minimum initial load (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load required for gasket seating W_{m2} shall be determined in accordance with eq. (2):

$$W_{m2} = 0.637 H_m \tan\left(\phi + \mu\right) \tag{2}$$

(3) To assure proper preloading of the clamp connection against operating conditions, an assembly bolt load W_{m3} shall be determined in accordance with eq. (3):

$$W_{m3} = 0.637\left(H + H_p\right)\tan\left(\phi + \mu\right) \tag{3}$$

(4) In eq. (1)(1), credit for friction is allowed based on clamp connection geometry and experience, but the bolt load shall not be less than that determined using a $\phi - \mu$ value of 5 deg. Friction is also considered in determining bolt loads by eqs. (2)(2) and (3)(3), but the μ factor used shall not be less than 5 deg.

(c) Required Bolt Area. The total cross-sectional area of bolting A_{mL} required shall be the greater of the values for operating conditions A_{m1}, gasket seating conditions A_{m2}, or assembly condition A_{m3}. Bolt bending in the assembly shall be avoided by utilization of spherically seated nuts and/or washers.

(d) Clamp Connection Design Bolt Load W. The bolt load used in the design of the clamp connection shall be the value obtained from eqs. (4) and (5).

Operating conditions:

$$W = W_{m1} \tag{4}$$

Assembly conditions:

$$W = \left(A_{mL} + A_{bL}\right)S_a \tag{5}$$

Alternatively, if controlled bolting (e.g., bolt tensioning or torque control) techniques are used to assemble the clamp, the assembly design bolt load may be taken as

$$W = 2A_{mL} \cdot S_a \tag{6}$$

In addition, the Manufacturer shall provide to the User a copy of the bolting instructions that were used. It is recommended that the Manufacturer refer to ASME PCC-1, Guidelines for Pressure Boundary Bolted Flange Joint Assembly.

It is cautioned that bolt loads in excess of those calculated using eq. (6) can overstress the clamp.

UCC-5 HUB MOMENTS

The moments used in determining hub stresses are the products of loads and moment arms illustrated in Figure UCC-1 and defined in UCC-3.

In addition, reaction moments due to hub eccentricities and bearing pressure are considered.

For the operating condition, the design moment M_o is the sum of six individual moments: M_D, M_G, M_T, M_F, M_P, and M_R. The bolt load W used is that from eq. UCC-4(d)(4).

For assembly, the design moment M_o is based on the design bolt load of eq. UCC-4(d)(5):

$$M_o = \frac{0.785W(C-G)}{\tan(\phi + \mu)} \tag{7}$$

UCC-6 CALCULATION OF HUB STRESSES

The stresses in the hub shall be determined for both the operating and the assembly condition.

(a) The reaction moment M_H and the reaction shear Q are defined in UCC-3 and shall be calculated at the hub neck for rotational moment M_o.

(b) Hub stresses shall be calculated from the following equations:

Hub longitudinal stress

$$S_1 = f\left[\frac{PB^2}{4g_1\left(B + g_1\right)} + \frac{1.91M_H}{g_1{}^2\left(B + g_1\right)}\right] \tag{8}$$

Hub hoop stress

$$S_2 = P\left(\frac{N^2 + B^2}{N^2 - B^2}\right) \tag{9}$$

Hub axial shear stress

$$S_3 = \frac{0.75\,W}{T\left(B + 2g_1\right)\tan Z} \tag{10}$$

Hub radial shear stress

$$S_4 = \frac{0.477\,Q}{g_1\left(B + g_1\right)} \tag{11}$$

UCC-7 CALCULATION OF CLAMP STRESSES

The stresses in the clamp shall be determined for both the operating and the assembly conditions. Clamp stresses shall be calculated from the following equations:

Clamp longitudinal stress

$$S_5 = \frac{W}{2C\tan Z}\left[\frac{1}{C_t} + \frac{3\left(C_t + 2l_m\right)}{C_t^2}\right] \tag{12}$$

Clamp tangential stress

$$S_6 = \frac{W}{2}\left[\frac{1}{A_c} + \frac{|e_b|\left(C_t - X\right)}{I_c}\right] \tag{13}$$

Clamp lip shear stress

$$S_7 = \frac{1.5\,W}{\left(C_w - C_g\right)C\tan Z} \tag{14}$$

Clamp lug bending stress

$$S_8 = 3W\frac{L_a}{L_w L_h{}^2} \tag{15}$$

In addition, a bearing stress calculation shall be made at the clamp-to-hub contact by eq. (16):

$$S_9 = \frac{W}{(A - C_i)\, C \tan Z} \qquad (16)$$

UCC-8 ALLOWABLE DESIGN STRESSES FOR CLAMP CONNECTIONS

Table UCC-8 gives the allowable stresses that are to be used with the equations of UCC-6 and UCC-7.

Table UCC-8
Allowable Design Stress for Clamp Connections

Stress Category	Allowable Stress
S_1	1.5 S_{OH} or 1.5 S_{AH}
S_2	S_{OH}
S_3	0.8 S_{OH} or 0.8 S_{AH}
S_4	0.8 S_{OH} or 0.8 S_{AH}
S_5	1.5 S_{OC} or 1.5 S_{AC}
S_6	1.5 S_{OC} or 1.5 S_{AC}
S_7	0.8 S_{OC} or 0.8 S_{AC}
S_8	S_{OC} or S_{AC}
S_9	[Note (1)]

NOTE:
(1) 1.6 times the lower of the allowable stresses for hub material (S_{OH}, S_{AH}) and clamp material (S_{OC}, S_{AC}).

PART UDA DIMPLED OR EMBOSSED ASSEMBLIES

(25)

UDA-1 SCOPE

(a) The rules in this Part cover minimum requirements for the design, fabrication, and examination of pressure vessel assemblies limited to the following types:

(1) dimpled or embossed prior to welding;

(2) dimpled or embossed form achieved by using hydraulic or pneumatic pressure after welding.

(b) Welding processes covered under the rules of this Part include "weld-through" processes in which welding is done by penetrating through one or more members into, but not through, another member (see Figures UDA-1-1 through UDA-1-6). These welding processes are as follows:

(1) resistance spot welding;

(2) resistance seam welding;

(3) gas-metal arc spot welding in which a spot weld is produced between two overlapping metal parts by heating with a timed electric arc between a consumable metal electrode and the work. The spot weld is made without preparing a hole in either member or with a hole in the dimpled or embossed member. Filler metal is obtained from the consumable electrode, and shielding is obtained from a single gas, a gas mixture (which may contain an inert gas), or a gas and a flux. See Figure UDA-1-4.

(4) machine, automatic, or semiautomatic gas tungsten arc seam welding without the addition of filler metal;

(5) machine, automatic, or semiautomatic gas tungsten-arc spot welding without the addition of filler metal;

(6) machine or automatic plasma arc seam welding without the addition of filler metal;

(7) machine or automatic submerged-arc seam welding with filler metal obtained from the electrode and shielding provided by the flux;

(8) machine or automatic laser beam seam welding without the addition of filler metal.

(c) Welding processes covered under the rules of this Part defined as "complete penetration" processes in which welding penetrates through all members to be joined (see Figure UDA-1-7) are as follows:

(1) machine or automatic laser beam seam welding without the addition of filler metal

(2) plasma arc seam welding with or without the addition of filler metal

(d) For the purposes of specifying special requirements and degree of examination, the weld joints made by the processes covered under the rules of this Part shall be considered as Category C joints.

(e) Embossed or dimpled assemblies may be made in one or more of the following manners:

(1) two embossed or two dimpled plates welded together as shown in Figures UDA-1-1 and UDA-1-2 or an embossed or dimpled plate welded to a plain plate as shown in Figures UDA-1-3, UDA-1-4, and UDA-1-5 using a welding process described in (b) or (c) above;

(2) two outer embossed or two outer dimpled plates welded to a third, intermediate plate, frame, or series of spacers to form a three-ply assembly as shown in Figure UDA-1-6 using a welding process described in (b)(1) or (b)(2) above.

(f) Dimpled or Embossed Assemblies, which consist of a dimpled or embossed plate welded to another like plate or to a plain plate and for which the welded attachment is made by fillet welds around holes or slots, shall be constructed in accordance with the requirements of UW-19(c).

(g) The minimum thickness limitations of UG-16.2 and UG-16.3 do not apply to Dimpled and Embossed Assemblies designed to this Part.

UDA-2 SERVICE RESTRICTIONS

(a) Assemblies as defined in this Part shall not be used for the containment of substances defined as lethal by UW-2(a).

(b) Assemblies defined in UDA-1(a)(2) shall not be used as unfired steam boilers or as vessels subject to direct firing.

(c) *Low Temperature Operation*. Welds made in accordance with UDA-1(b)(1) and UDA-1(b)(2) do not require qualification with toughness testing when joining permitted Parts UHA and UNF materials.

UDA-3 MATERIALS

Materials used in the pressure-containing parts of vessels covered by this Part shall be limited to those permitted by other parts of this Section or Division and qualified for welding per UDA-7.

UDA-4 THICKNESS LIMITATIONS

The range of thickness of pressure-containing parts which may be welded under the provisions of this Part shall be limited to that qualified by the welding procedure under the provisions of UDA-7. The nominal thickness for plate shall not be less than 0.030 in. (0.8 mm).

UDA-5 MAXIMUM ALLOWABLE WORKING PRESSURE (MAWP)

The MAWP shall be the lowest pressure established by (a) and (b) below.

(a) Proof Test

(1) For assemblies constructed under the provision of UDA-1(a)(1), a proof test shall be conducted in accordance with UG-101. In using the formulas for calculating the MAWP, a value of 0.8 shall be used for E, the weld joint efficiency factor. This test may be a separate test or part of the test in UDA-7(a)(1)(-a).

(2) For assemblies constructed under the provisions of UDA-1(a)(2), a proof test shall be conducted in accordance with the requirements of UG-101 using the bursting test procedures of UG-101(m) except provisions of UG-101(c) need not be followed provided that, when performing the proof test, the application of pressure is continuous until burst or until the proof test is stopped. In using the formulas for calculating the maximum allowable working pressure, a value of 0.80 shall be used for E, the weld joint efficiency factor. If the spot-welded and seam-welded sheets are formed to any shape other than flat plates prior to the inflating process which results in the dimpled formation, the proof tested vessel or representative panel shall be of a configuration whose curvature is to a radius no greater than that which will be used in production vessels. The representative panel shall utilize the same weld details as will be used in the final construction.

(b) Calculations

(1) For assemblies using plain plate welded in accordance with UDA-1(b)(2), UDA-1(b)(4), UDA-1(b)(6), UDA-1(b)(7), UDA-1(b)(8), and UDA-1(c), calculate the MAWP or minimum thickness of the plain plate by the following formulas:

$$P = \frac{3St^2}{p^2} \tag{1}$$

$$t = p\sqrt{\frac{P}{3S}} \tag{2}$$

where

P = internal design pressure (see UG-21), psi (kPa)
p = maximum pitch measured between adjacent seam weld center lines, in. (mm)
S = maximum allowable stress value given in Section II, Part D, psi (kPa)
t = minimum thickness of plate, in. (mm)

(2) For assemblies using plain plate welded in accordance with UDA-1(b)(1), UDA-1(b)(3), and UDA-1(b)(5), calculate the MAWP of the plain plate in accordance with the requirements for braced and stayed surfaces. See UG-47.

UDA-6 DESIGN LIMITATIONS

For assemblies constructed under the provisions of UDA-1(a)(2), the following design limitations shall apply:

(a) A change in any of the following variables will require requalification of the design using the proof test of UDA-5(a)(2):

(1) an increase in the spot or seam pitch exceeding $^1/_{16}$ in. (1.5 mm);

(2) a change in the specification, type, thickness, or grade of material for either sheet or both sheets;

(3) a change in the electrode size or electrode material;

(4) in formed construction when the radius of the curvature is less than the radius in the proof section [see UDA-5(a)(2)].

(b) A test panel duplicating that used to establish the maximum allowable working pressure shall be inflated to a pressure at least 5% greater than the maximum forming pressure to be used in production. The rate of pressurization shall be the same as that used in the burst test. The panel shall be sectioned to show at least six spot welds (see Figure UDA-6-1). The weld cross sections shall be subjected to macroetch examinations and shall show no cracks. The maximum pillow heights measured, as shown in Figure UDA-6-2, of vessels made in production shall not exceed 95% of the maximum pillow height of this duplicate test panel. The maximum forming pressure shall not exceed 80% of the burst pressure.

UDA-7 WELDING CONTROL

(a) Welding Procedure Qualification shall be performed in accordance with the requirements of (1). Performance Qualification shall be performed in accordance with Section IX or one of the following alternative requirements:

(1) Proof Testing for Procedure and Performance Qualification

(-a) For assemblies constructed under the provisions of UDA-1(a)(1), a pressure proof test to destruction shall be conducted on a finished vessel or representative panel. The test shall be conducted as specified in UG-101(m). If a representative panel is used, it shall be rectangular in shape and at least 5 pitches in each direction, but not less than 24 in. (600 mm) in either direction.

(-b) For assemblies constructed under the provisions of UDA-1(a)(2), a pressure proof test to destruction as set forth in UDA-5(a)(2) shall be conducted on a finished vessel or representative panel. This test may be a

separate test or a part of the test in UDA-5(a)(2). If a representative panel is used, it shall be rectangular in shape and at least 5 pitches in each direction but not less than 24 in. (600 mm) in either direction.

(-c) Duplicate parts or geometrically similar parts that are fabricated using the same welding process, and meet the requirements of UG-101(d)(1) or UG-101(d)(2), need not be tested.

(2) Workmanship Samples

(-a) For assemblies for two-ply joints constructed under the provisions of UDA-1(b)(1), UDA-1(b)(2), UDA-1(b)(4), UDA-1(b)(5), UDA-1(b)(6), UDA-1(b)(7), UDA-1(b)(8), or UDA-1(c), three single spot welded specimens or one seam welded specimen, as shown in Figures UDA-7-1 and UDA-7-2, shall be made immediately before and after the welding of the proof test vessel.

Similarly, for assemblies for three-ply joints constructed under the provisions of UDA-1(b)(1) and/or UDA-1(b)(2), three single spot welded specimens and/or one seam welded specimen, as shown in Figures UDA-7-3 and UDA-7-4 for three-ply joints shall be made immediately before and after welding of the proof test vessel. These test specimens shall be representative of the manufacturing practice employed in the fabrication of the proof test vessel.

When resistance welding and a difference in the amount of magnetic material in the throat of the machine or the part geometry preclude the welding of satisfactory test specimens at the same machine settings as those used for the proof test vessel, sufficient material shall be placed in the throat of the welding machine to compensate for the difference in size of the proof test panel and the small test specimens.

The spot welded specimens shall be subjected to tensile loading for ultimate strength and be visually inspected for nugget size, electrode indentation, and evidence of defects. The seam weld specimens shall be similarly tested for ultimate strength and prepared for macrographic examination to reveal nugget size, spacing, penetration, soundness, and surface condition. In addition, a typical spot welded sample and seam welded sample shall be cut from the proof test vessel or panel after failure. A portion of each sample shall be sectioned for macroetch examination.

Also for two-ply assemblies constructed under the provisions of UDA-1(b)(4), UDA-1(b)(6), UDA-1(b)(7), UDA-1(b)(8), or UDA-1(c), additional test specimens as shown in Figure UDA-7-5 shall be made; one immediately before and one immediately after the welding of the proof test vessel, using the same plate thicknesses and material grade used in the proof test vessel. These welds shall be representative of the manufacturing practice employed in the fabrication of the proof test vessel and of the practice to be used for the production vessels. One cross section shall be taken from each weld test assembly, as shown in Figure UDA-7-5, and shall be suitably polished and etched to show clearly the demarcation between the weld metal and the base metal. The etched macrosections shall reveal sound weld metal with complete fusion along the bond line and complete freedom from cracks in the weld metal and the heat affected base metals. The width of the weld at the interface shall be measured and recorded as a workmanship reference value.

Bend tests shall be made on each of the test weld assemblies, as shown in Figure UDA-7-5. The bend specimens shall be tested in accordance with Section IX, QW-160, except that after bending, the convex surface of the specimens, in the weld and the heat affected base metal, shall show not more than two cracks or other open defects, neither of which shall measure more than $^1/_{16}$ in. (1.5 mm) in length in any direction.

One cross section from each of any two welds constructed under the provisions of UDA-1(b)(4), UDA-1(b)(6), UDA-1(b)(7), UDA-1(b)(8), or UDA-1(c) shall be cut from the proof test vessel after failure and these shall be subjected to macroetch examination as above.

(-b) For assemblies constructed under the provision of UDA-1(b)(3), a test block of five or more arc-spot welds, as shown in Figure UDA-7-6, shall be made immediately before and after welding of the proof test vessel, using the same plate thickness and material of the same specification and grade as used in the proof test vessel. These welds shall be representative of the manufacturing practice employed in the fabrication of the proof test vessel and of the practice to be used for the production vessels. The arc-spot welds shall be visually inspected for surface soundness, fusion, and external nugget shape and size D_o. At least three welds from each test block shall be cross-sectioned and suitably etched to show clearly the demarcation between the weld metal and the base metal. The etched macrosections shall reveal sound weld metal with complete fusion along the bond line and complete freedom from cracks in the weld metal and the heat affected base metals. The nugget diameter D_i at the faying surface shall be reasonably consistent in all specimens, and the penetration P_2 into the backup member shall be less than the thickness t_2 of that member. At least two welds from each test block shall be broken in tension or peel-tested. In addition to the test-block welds, five or more typical arc-spot weld samples shall be cut from the proof test vessel, after it has been tested to destruction, for cross sectioning and macroscopic examination for nugget size, penetration, and configuration. Any combination of carbon steels P-No. 1 material listed in Table UCS-23 shall be considered as a similar-material combination. Any combination of stainless steels listed in Table UHA-23 shall be considered as a similar-material combination. Any combination of nonferrous materials listed in Tables UNF-23.1 through UNF-23.5 shall be considered as a similar-material combination. For qualification of arc-spot welds in dissimilar combinations of carbon steels, stainless steels, and SB-168 (Ni–Cr–Fe alloy), an additional block of four arc-spot welds shall be prepared

for bend tests, as shown in Figure UDA-7-7, immediately before and after the welding of the proof test vessel. The bend specimens shall be tested in accordance with Section IX, Figures QW-466.1 through QW-466.6, except that after bending, the convex surface of the specimens, in the weld and the heat-affected base metal, shall show not more than two cracks or other open defects, neither of which shall measure more than $^{1}/_{16}$ in. (1.5 mm) in length in any direction.

(b) Machine Settings and Controls

(1) For vessels constructed under the provisions of this Part, all applicable parameters used in the making of the proof test vessel and workmanship samples shall be recorded. Parameters to be recorded are as follows:

(-a) all Essential, Nonessential, and Supplementary Essential (if required) Variables listed in Section IX for procedure qualifications of the applicable process;

(-b) all preheat, postweld heat treatments, and examination procedures;

(-c) applicable material specification, including type, grade, and thickness of the material welded;

(-d) parameters recorded above shall be included in a written Welding Procedure Specification and will serve as procedure and performance qualifications for future production.

(2) Except for minor variations permitted by the welding variables in Section IX, the settings recorded per (1) above shall be used in the fabrication of all vessels in a given production run. See UDA-8(a)(1).

(3) If equipment other than that used for the initial proof test vessel and the workmanship samples is to be used in production, each additional machine and welding procedure shall be qualified in full accordance with (1) above or in accordance with the requirements in Section IX. In assemblies welded per UDA-1(b)(3), any major component change or replacement of welding equipment previously qualified shall require requalification. (Routine maintenance and replacement of expendable items, such as contact tubes and shielding nozzles, are excluded.)

(c) Miscellaneous Welding Requirements

(1) Lap joints may only be resistance spot or seam welded per UDA-1(b)(1) or UDA-1(b)(2); or machine, automatic, or semiautomatic gas tungsten-arc welded per UDA-1(b)(4) or UDA-1(b)(5); or machine or automatic plasma-arc welded per UDA-1(b)(6); or machine or automatic submerged-arc welded per UDA-1(b)(7); or machine or automatic laser beam welded per UDA-1(b)(8) or UDA-1(c).

(2) For assemblies welded per UDA-1(b)(3), the gas metal arc-spot welding equipment used in the qualification tests and in production shall be semiautomatic (with a timed arc) or fully automatic. Manual arc-spot welding where the welder has manual control of arc time is not permitted under the rules of this Part, nor are edge or fillet type arc-spot welds. All gas metal arc-spot welding shall be done in the downhand position, with the work, at the location of the spot weld, in a substantially horizontal plane. The required size and spacing of the gas metal arc-spot welds shall be demonstrated by calculation and by the pressure proof test [see UDA-5(a)].

(3) For assemblies constructed under the provisions of UDA-1(a)(2), and having sheets formed within dies where the dies control the shape of the pillow (see Figure UDA-6-2) and restrain the welds so that the bending in the sheet is outside of the heat-affected zone, the welding may be done before or after forming; and the requirements and limitations of UDA-6(b) do not apply.

(d) Welding other than that permitted by this Part, used for the attachment of nozzles, tubes and fittings, for the closing of peripheral seams, for the making of plug and slot welds, or for the fillet welding of holes and slots, shall be conducted in accordance with the requirements of this Division.

UDA-8 QUALITY CONTROL

(a) Definitions

(1) production run — a group of vessels or assemblies all produced during the same 24 hr day using the same welding processes, materials, and material thicknesses

(2) peel test — a test performed in accordance with Figure UDA-8-1

(3) tension test — a destructive test performed in a tension test machine employing specimens shown in Figures UDA-7-1, UDA-7-2, UDA-7-3, UDA-7-4, and UDA-7-6

(b) Test Requirements. At the beginning of each production run, at least one test shall be made as follows:

(1) For assemblies constructed under UDA-1(b)(1), UDA-1(b)(2), UDA-1(b)(4), UDA-1(b)(5), UDA-1(b)(6), UDA-1(b)(7), UDA-1(b)(8), or UDA-1(c), a peel test, a tension test, or a macroetch examination shall be performed. The acceptance criteria for the peel and tension tests shall be that the parent metal adjacent to the weld must fail before the weld itself fails. The macroetch examination shall be performed on one test specimen by cross sectioning and examining the weld in accordance with UDA-7(a)(2)(-b).

(2) For assemblies constructed under UDA-1(b)(3), a macroetch examination shall be performed in accordance with UDA-7(a)(2)(-b) except that only one weld need be cross sectioned and examined.

UDA-9 RECORDS

As specified in UDA-7(b), records shall be maintained for all data obtained during the fabrication of the proof test vessels and the workmanship samples. Such records shall also be kept for production work welded in accordance with UDA-1(b)(3), UDA-1(b)(4), UDA-1(b)(5), UDA-1(b)(6), UDA-1(b)(7), UDA-1(b)(8), and UDA-1(c).

UDA-10 DATA REPORTS

When all the requirements of this Division and the supplemental requirements of this Part have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance with Part UDA, Dimpled or Embossed Assemblies."

Figure UDA-1-1
Two Embossed Plates

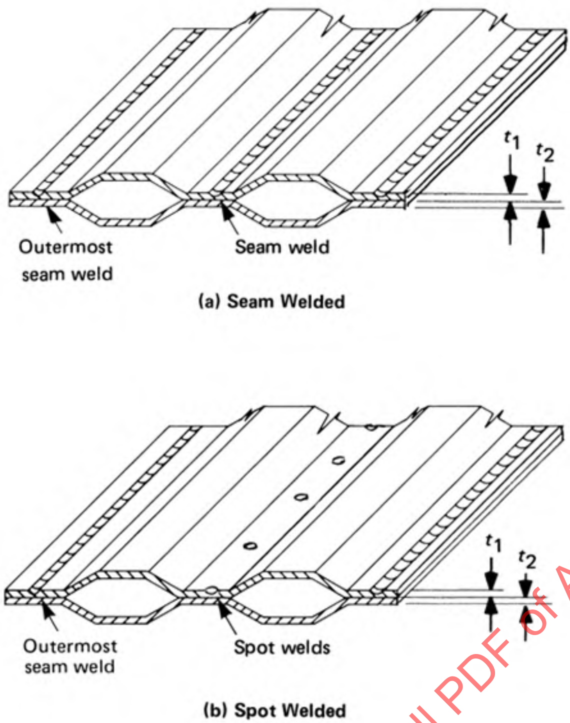


Figure UDA-1-2
Two Dimpled Plates

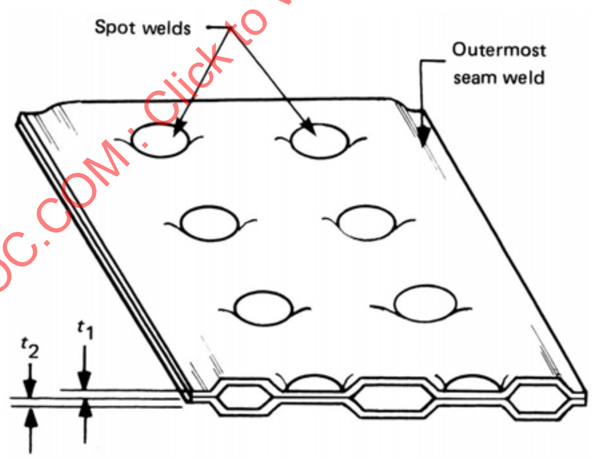


Figure UDA-1-3
Embossed Plate to Plain Plate

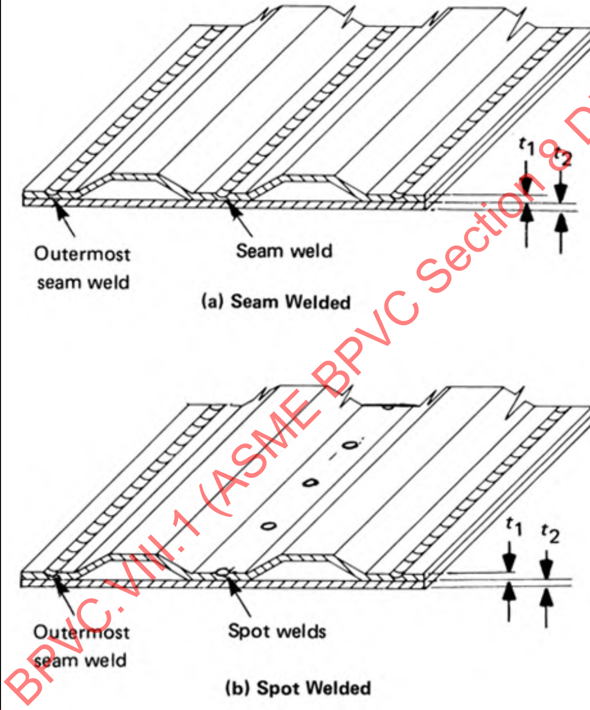


Figure UDA-1-4
Arc-Spot-Welded Two-Layer Assembly

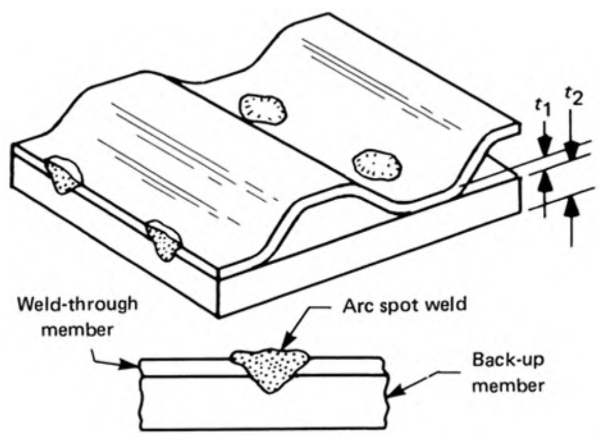


Figure UDA-1-5
Dimpled Plate Welded to Plain Plate

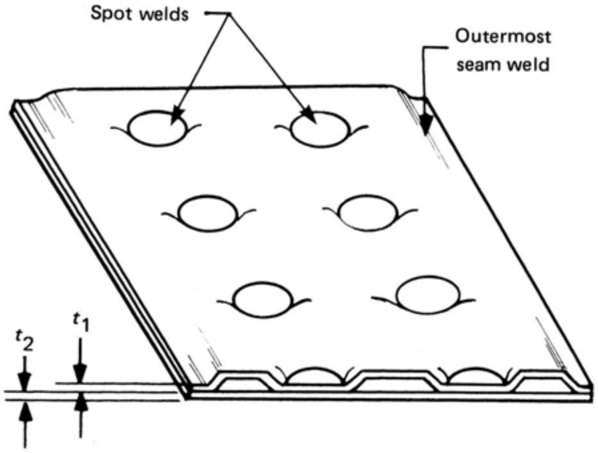


Figure UDA-1-6
Three-Ply Assemblies

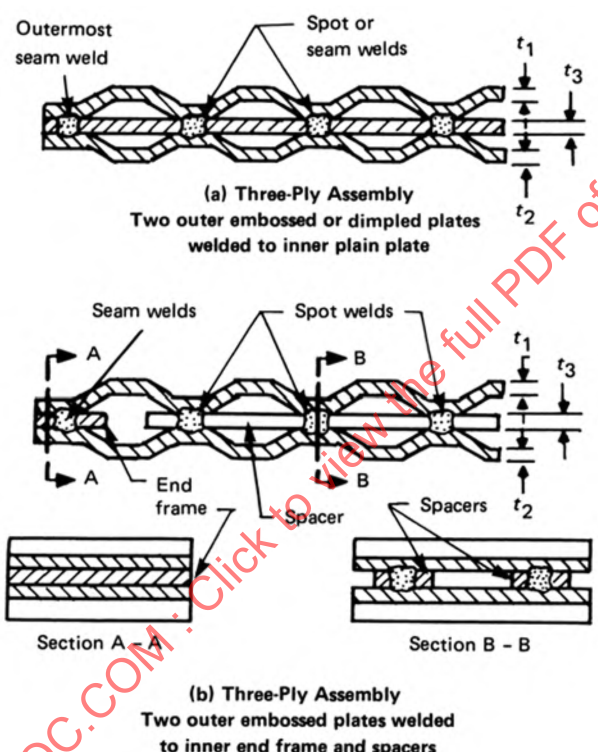


Figure UDA-1-7
Complete Penetration Welding Per UDA-1(c)

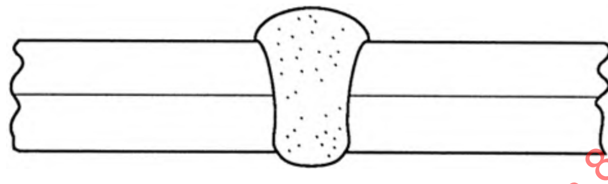


Figure UDA-6-1
Spot Weld Test Panel

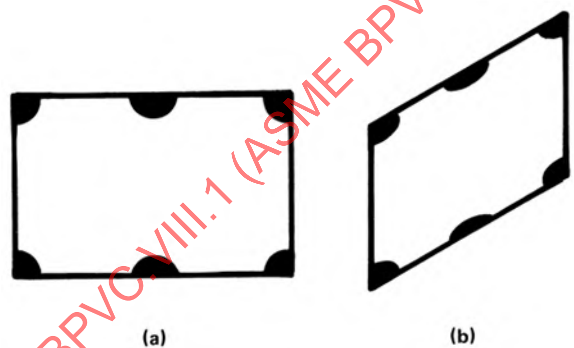


Figure UDA-6-2
Pillow Height

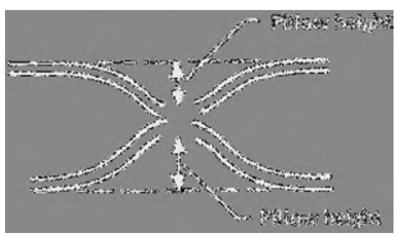
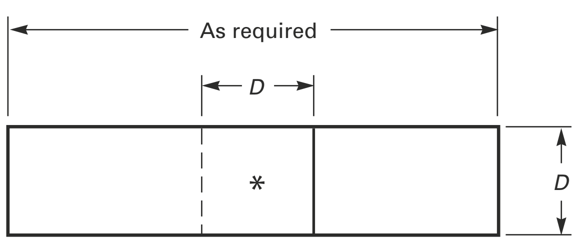
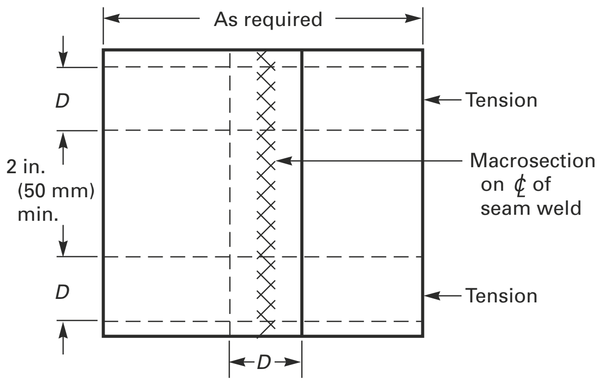


Figure UDA-7-1
Single-Spot-Weld Tension Specimen, Two-Ply Joint



GENERAL NOTE: 1 in. (25 mm) ≤ D ≤ $1\frac{1}{4}$ in. (32 mm).

Figure UDA-7-2
Seam-Weld Specimen for Tension and Macrosection, Two-Ply Joint



GENERAL NOTE: 1 in. (25 mm) ≤ D ≤ $1^1/_4$ in. (32 mm).

Figure UDA-7-3
Single Spot-Weld Tension Specimen for Three-Ply Joint

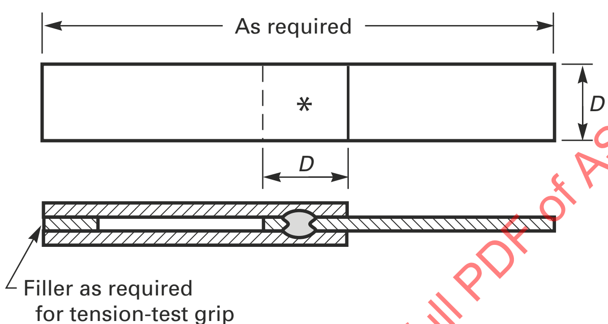
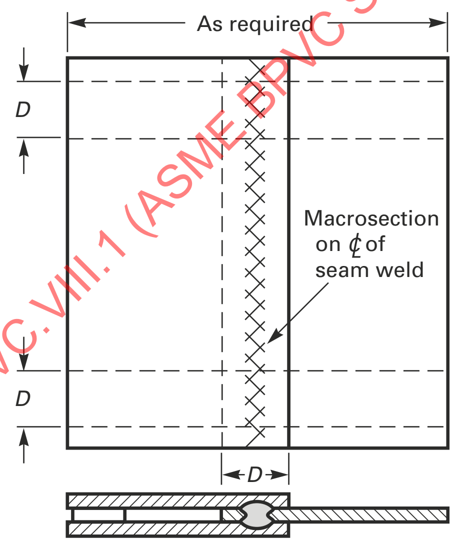


Figure UDA-7-3
Single Spot-Weld Tension Specimen for Three-Ply Joint (Cont'd)

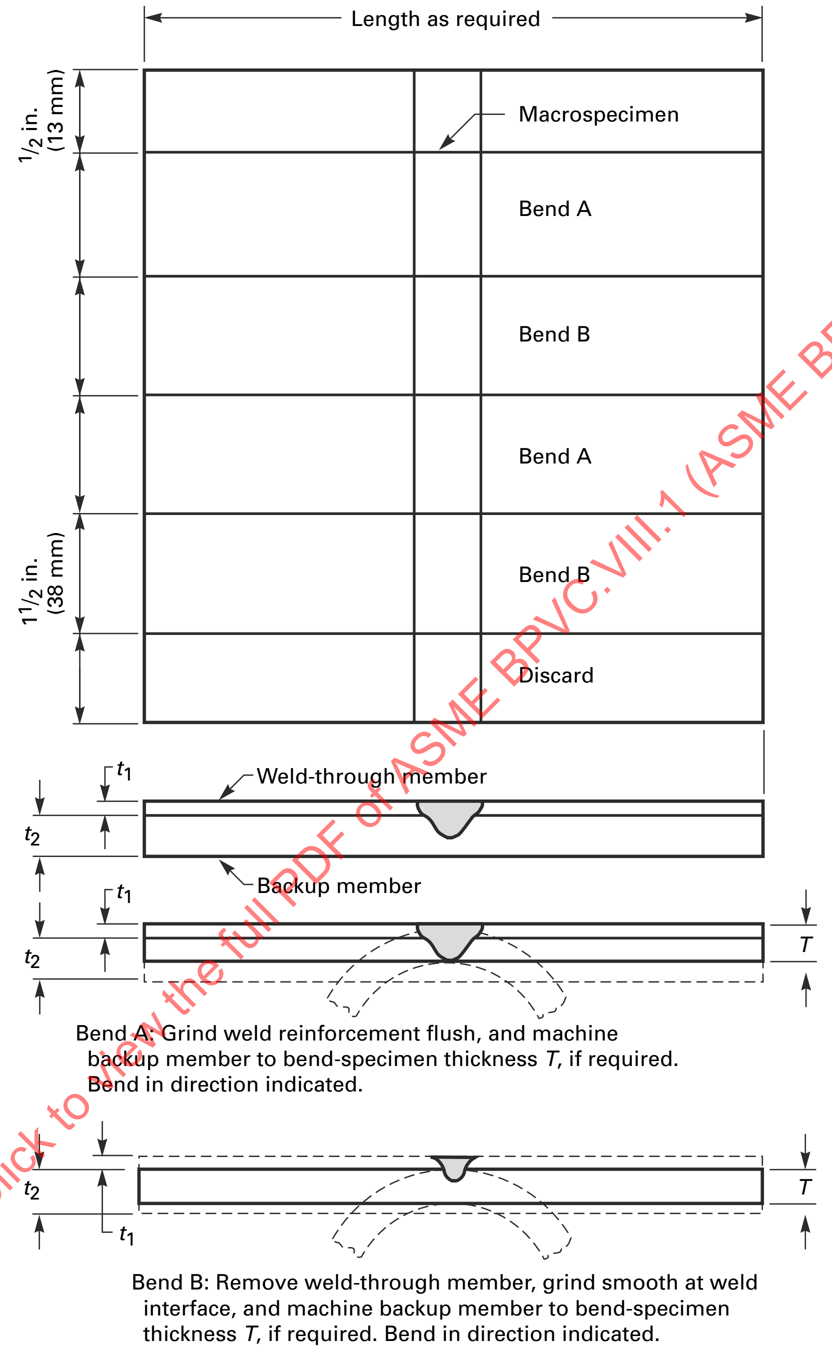
GENERAL NOTE: 1 in. (25 mm) ≤ D ≤ $1^1/_4$ in. (32 mm).

Figure UDA-7-4
Seam-Weld Specimen for Tension and Macrosection for Three-Ply Joint



GENERAL NOTE: 1 in. (25 mm) ≤ D ≤ $1^1/_4$ in. (32 mm).

Figure UDA-7-5
Gas Tungsten-Arc Seam Weld, Plasma-Arc Seam Weld, Submerged-Arc Seam Weld, and Laser Beam Seam Weld Test Specimen for Bend Tests



GENERAL NOTE: Refer to Section IX, Figures QW-462.3(a) and QW-462.3(b) and Figures QW-466.1 through QW-466.6.

Figure UDA-7-6
Gas Metal Arc-Spot-Weld Block for Macrosections and Strength Tests

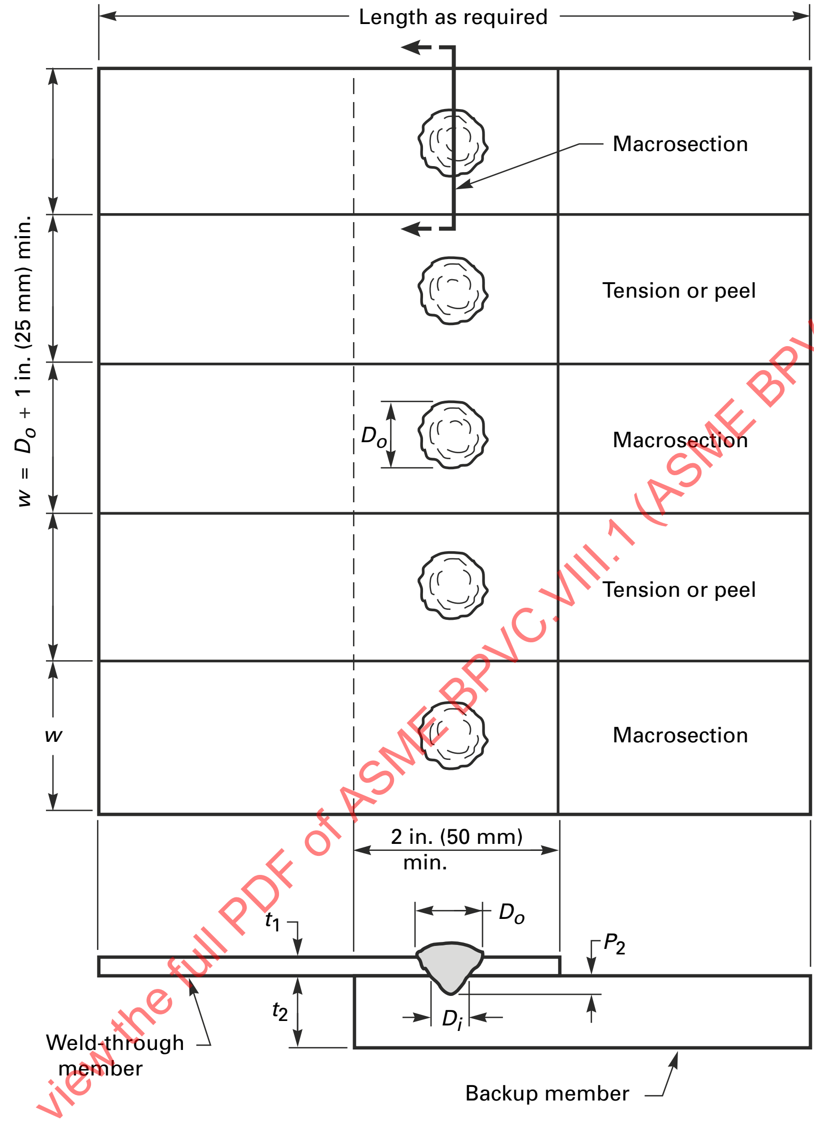
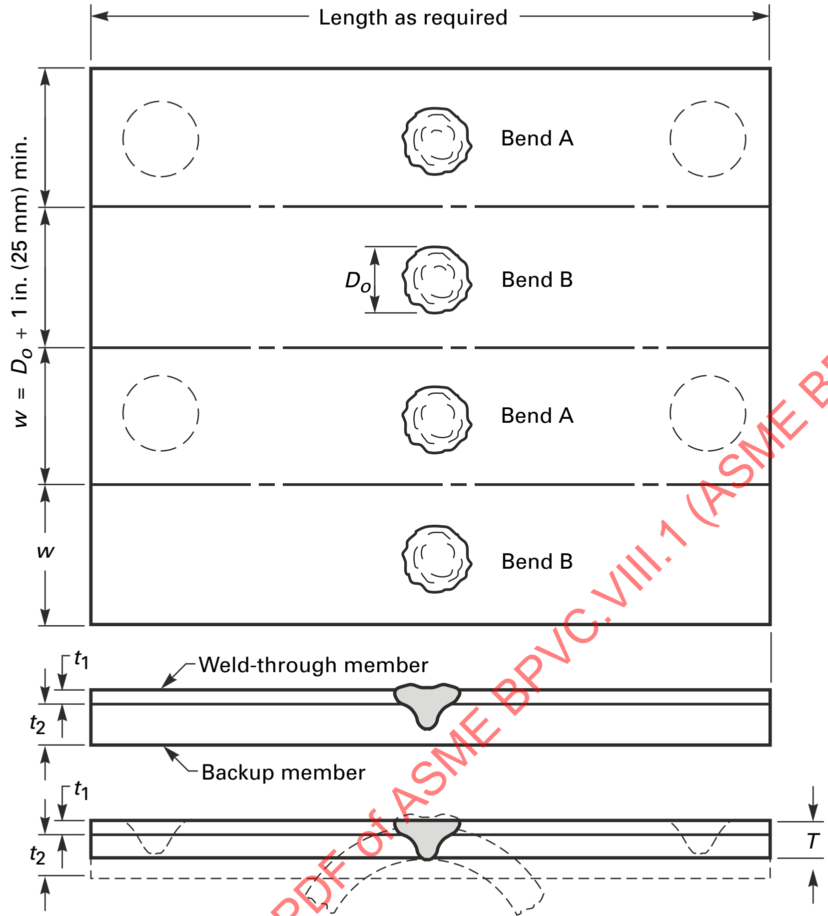
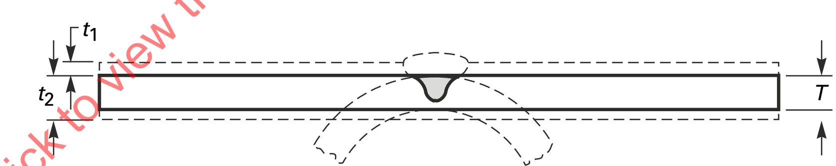


Figure UDA-7-7
Gas Metal Arc-Spot-Weld Block for Bend Tests

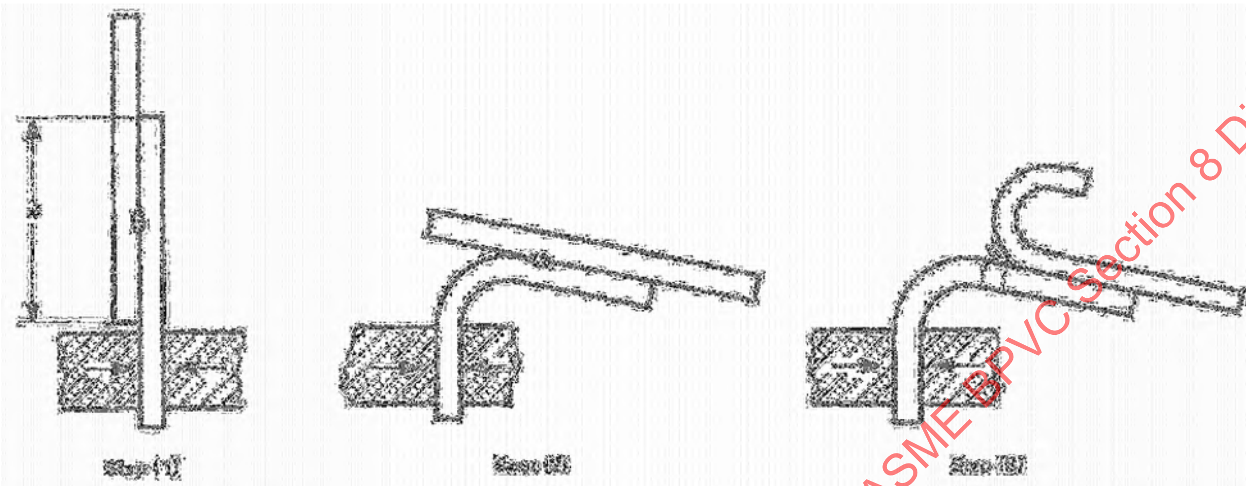


Bend A: Grind arc-spot weld reinforcement flush, and machine backup member to bend-specimen thickness T, if required. Bend in direction indicated.



Bend B: Remove weld-through member, grind smooth at arc-spot-weld (faying surface), and machine backup member to bend-specimen thickness T, if required. Bend in direction indicated.

Figure UDA-8-1
Peel Test



Step 1. Grip specimen in vise or other suitable device.
Step 2. Bend specimen. (This step may not be required if the gripped portion of the specimen is greatly thicker than the other portion.)
Step 3. Peel pieces apart with suitable tool until they are separated.

(25)

PART UEB
BELLOWS EXPANSION JOINTS

UEB-1 GENERAL

(a) The rules in this Part cover the minimum requirements for the design of bellows expansion joints used as an integral part of heat exchangers or other pressure vessels.

(1) These rules apply to single- or multiple-layer bellows expansion joints, unreinforced, reinforced, or toroidal, as shown in Section VIII, Division 2, Figure 4.19.1, subject to internal or external pressure and cyclic displacement. The bellows shall consist of single or multiple identically formed convolutions. They may be as formed (not heat treated) or annealed (heat treated). The suitability of an expansion joint for the specified design pressure, temperature, and axial displacement shall be determined by the methods described herein.

(2) Design requirements in Section VIII, Division 2 shall be used for bellows expansion joints in lieu of those previously listed in this Part except that the design for instability due to external pressure shall be performed according to the rules of UG-28 in lieu of 4.4 referenced in Section VIII, Division 2, 4.19.5.6(b).

(3) When a Part UEB section, paragraph, table, or graph is referenced, the applicable section of Division 2 shall be used in accordance with UG-16 and Mandatory Appendix 46 (see 46-2 and 46-3).

(4) Requirements other than design shall be in accordance with this Part.

(b) The rules in this Part cover the common types of bellows expansion joints but are not intended to limit the configurations or details to those illustrated or otherwise described herein. Designs that differ from those covered in this Part (e.g., asymmetric geometries or loadings) shall be in accordance with U-2(g) in lieu of the requirements provided in Section VIII, Division 2, 4.1.1.2 referenced in 4.19.1(b).

(c) The design rules in this Part are valid for design temperatures (see UG-20) up to the temperatures shown in Table UEB-1-1. Above these temperatures, the effects of time-dependent behavior (creep and creep–fatigue interaction) shall be considered in accordance with U-2(g).

(d) The vessel manufacturer shall specify the design conditions and requirements for the detailed design and manufacture of the expansion joint. Use of Specification Sheet Form UEB-1 (Form UEB-1M) is recommended.

UEB-5 MATERIALS

Pressure-retaining component materials, including the restraining elements (e.g., exchanger tubes or shell, external restraints, anchors), shall comply with the requirements of UG-4. The stress [see UG-23(c)] in these restraining elements shall not exceed the maximum allowable stress at the design temperature for the material given in the tables referenced by UG-23.

UEB-10 FABRICATION

(a) Longitudinal weld seams shall be butt-type full penetration welds; Type (1) of Table UW-12.

(b) Circumferential welds attaching the bellows to the shell or weld end elements shall be full penetration groove welds or full fillet welds as shown in Figure UEB-13.

(c) Other than the attachment welds, no circumferential welds are permitted in the fabrication of bellows convolutions.

(d) U-shaped unreinforced and reinforced bellows shall be manufactured to the tolerances listed in Table UEB-10-1.

(e) Toroidal bellows shall be manufactured to the tolerances shown in Figure UEB-14.

UEB-11 EXAMINATION

(a) Expansion joint flexible elements shall be visually examined and found free of unacceptable surface conditions, such as notches, crevices, material buildup or

Table UEB-1-1
Maximum Design Temperatures for Application of the Rules of Part UEB

Table in Which Material Is Listed	Maximum Temperature, °F	Maximum Temperature, °C
UNF-23.1	300	150
UNF-23.3	800	425
UNF-23.4	600	315
UNF-23.5	600	315
UHA-23	800	425

Table UEB-10-1
U-Shaped Unreinforced and Reinforced Bellows Manufacturing Tolerances

Bellows Dimension, in. (mm)	Manufacturing Tolerance, in. (mm)
Convolution pitch, *q*	
≤0.5 (≤12.7)	±0.063 (±1.6)
>0.5 to 1.0 (>12.7 to 25.4)	±0.125 (±3.2)
>1.0 to 1.5 (>25.4 to 38.1)	±0.188 (±4.7)
>1.5 to 2.0 (>38.1 to 50.8)	±0.250 (±6.4)
>2.0 (>50.8)	±0.313 (±7.9)
Convolution height, *w*	
≤0.5 (≤12.7)	±0.031 (±0.8)
>0.5 to 1.0 (>12.7 to 25.4)	±0.063 (±1.6)
>1.0 to 1.5 (>25.4 to 38.1)	±0.094 (±2.4)
>1.5 to 2.0 (>38.1 to 50.8)	±0.125 (±3.2)
>2.0 to 2.5 (>50.8 to 63.5)	±0.156 (±4.0)
>2.5 to 3.0 (>63.5 to 76.2)	±0.188 (±4.7)
>3.0 to 3.5 (>76.2 to 88.9)	±0.219 (±5.6)
>3.5 to 4.0 (>88.9 to 101.6)	±0.250 (±6.4)
>4.0 (>101.6)	±0.281 (±7.1)
Convolution inside diameter, D_b	
≤8.625 (≤219)	±0.063 (±1.6)
>8.625 to 24.0 (>219 to 610)	±0.125 (±3.2)
>24.0 to 48.0 (>610 to 1 219)	±0.188 (±4.7)
>48.0 to 60.0 (>1 219 to 1 524)	±0.250 (±6.4)
>60.0 (>1 524)	±0.313 (±7.9)

upsetting, and weld spatter, which may serve as points of local stress concentration. Suspect surface areas shall be further examined by the liquid penetrant method.

(b) Bellows butt-type welds shall be examined 100% on both sides by the liquid penetrant method before forming. This examination shall be repeated after forming to the maximum extent possible considering the physical and visual access to the weld surfaces after forming.

(c) The circumferential attachment welds between the bellows and the weld ends shall be examined 100% by the liquid penetrant method.

(d) Liquid penetrant examinations shall be in accordance with Mandatory Appendix 8, except that linear indications shall be considered relevant if the dimension exceeds $0.25t_m$, but not less than 0.010 in. (0.25 mm), where t_m is the minimum bellows wall thickness before forming.

UEB-12 PRESSURE TEST REQUIREMENTS

UEB-12.2 TEST REQUIREMENTS

(a) The completed expansion joint shall be pressure tested in accordance with UG-99 or UG-100. The pressure testing may be performed as a part of the final vessel pressure test, provided the joint is accessible for inspection during pressure testing.

(b) Expansion joint restraining elements [see Section VIII, Division 2, 4.19.3] shall also be pressure tested in accordance with UG-99 or UG-100 as a part of the initial expansion joint pressure test or as a part of the final vessel pressure test after installation of the joint.

(c) In addition to inspecting the expansion joint for leaks and structural integrity during the pressure test, expansion joints shall be inspected before, during, and after the pressure test for visible permanent distortion.

UEB-13 MARKING AND REPORTS

The expansion joint Manufacturer, whether the vessel Manufacturer or a parts Manufacturer, shall have a valid ASME Code U Certificate of Authorization and shall complete the appropriate Data Report in accordance with UG-120.

(a) The Manufacturer responsible for the expansion joint design shall include the following additional data and statements on the appropriate Data Report:

(1) spring rate

(2) axial movement (+ and −), associated design life in cycles, and associated loading condition, if applicable

(3) that the expansion joint has been constructed to the rules of this Part

(b) A parts Manufacturer shall identify the vessel for which the expansion joint is intended on the Partial Data Report.

(c) Markings shall not be stamped on the flexible elements of the expansion joint.

UEB-14 EXAMPLES

See U-16(c).

Figure UEB-13
Some Typical Expansion Bellows to Weld End Details

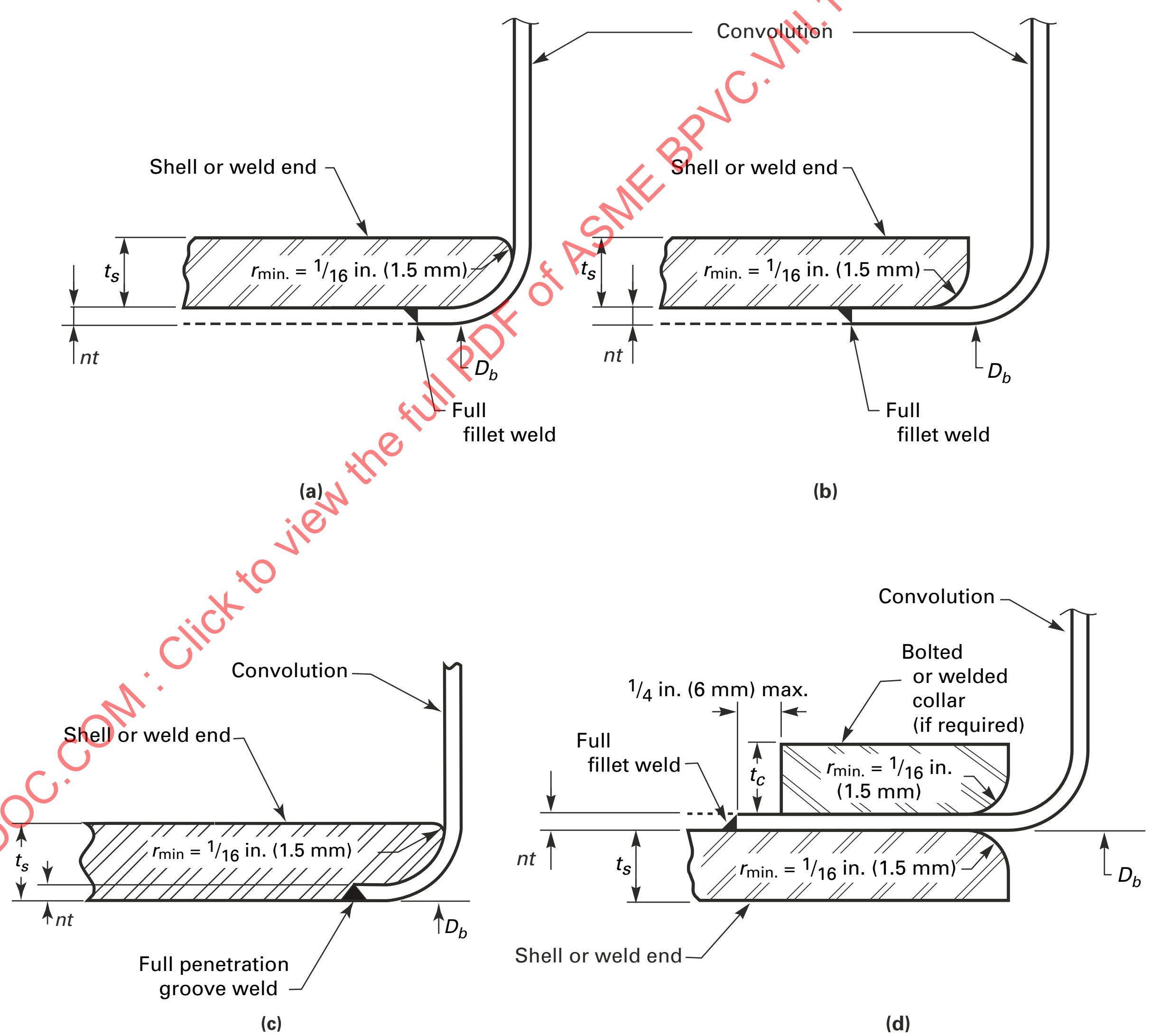
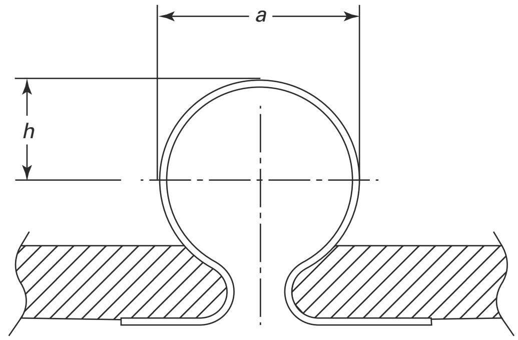


Figure UEB-14
Toroidal Bellows Manufacturing Tolerances



$$0.8 \leq \frac{a}{2h} \leq 1.2$$

(25)

FORM UEB-1 SPECIFICATION SHEET FOR ASME SECTION VIII, DIVISION 1 PART UEB BELLOWS EXPANSION JOINTS

Date _______ / ______ / ______ Applicable ASME Code Edition ________________

1. Item Number _____________ Vessel Manufacturer ______________________________
2. Drawing/Tag/Serial/Job Number _____________ Vessel Owner ____________________________________
3. Quantity __________ Installation Location ______________________________
4. Size _______ O.D. ______ I.D. in. Expansion Joint Overall Length __________ in.

5. Internal Pressure: Design _______ psig
6. External Pressure: Design _______ psig
7. Vessel Manufacturer Hydrotest Pressure: Internal _______ psig External ______ psig

8. Temperature: Design _______ °F Operating _____ °F Upset ______ °F
9. Vessel Rating: MAWP _______ psig MDMT _______ °F Installed Position: Horiz. ___ Vert. ___

10. Design Movements [Note (1)]:
Axial Compression (–) _______ in. Axial Extension (+) _______ in. Lateral _______ in. Angular _______ deg
11. Specified Number of Cycles _______________
12. Design Torsion: Moment _______________ in.-lb or Twist Angle ____________________________ deg

13. Shell Material ______________________________ Bellows Material _________________________
14. Shell Thickness ___________ in. Shell Corrosion Allowance: Internal ______ in. External ______ in.
15. Shell Radiography: None / Spot / Full
16. End Preparation: Square Cut ___ Outside Bevel ___ Inside Bevel ___ Double Bevel ___ (Describe in Line 24 if special)
17. Heat Exchanger Tube Length Between Inner Tubesheet Faces ______ in.

(07/25)

FORM UEB-1 SPECIFICATION SHEET FOR ASME SECTION VIII, DIVISION 1 PART UEB BELLOWS EXPANSION JOINTS (Cont'd)

18. Maximum Bellows Spring Rate: N Y - ______ lb/in.

19. Internal Liner: N Y - Material ______

20. Drain Holes in Liner: N Y - Quantity/Size ______

21. Liner Flush With Shell I.D.: N Y - Telescoping Liners? N ____ Y____

22. External Cover: N Y - Material ______

23. Preproduction Approvals Required: N Y - Drawings / Bellows Calculations / Weld Procedures

24. Additional Requirements (e.g., bellows preset, ultrasonic inspection):

NOTE:

(1) For multiple movements, Design movements (line 10) can be replaced by operating movements, which should then be described under "Additional Requirements" (line 24). For each one of them, axial compression or axial extension, lateral deflection and angular rotation at each extremity of cycle, together with the specified number of cycles, should be indicated. When known, the order of occurrence of the movements should also be indicated.

(07/25)

(25)

FORM UEB-1M SPECIFICATION SHEET FOR ASME SECTION VIII, DIVISION 1 PART UEB BELLOWS EXPANSION JOINTS

Date _______ / ______ / ______ Applicable ASME Code Edition ________________

1. Item Number ___________ Vessel Manufacturer ____________________________
2. Drawing/Tag/Serial/Job Number ___________ Vessel Owner _________________________________
3. Quantity ________ Installation Location ____________________________
4. Size ______ O.D. ______ I.D. mm Expansion Joint Overall Length _________ mm

5. Internal Pressure: Design _______ MPa
6. External Pressure: Design _______ MPa
7. Vessel Manufacturer Hydrotest Pressure: Internal _______ MPa External ______ MPa

8. Temperature: Design _______ °C Operating _____ °C Upset ______ °C
9. Vessel Rating: MAWP _______ MPa MDMT _______ °C Installed Position: Horiz. __ Vert. __

10. Design Movements [Note (1)]:
    Axial Compression (–) _______ mm Axial Extension (+) _______ mm Lateral_______ mm Angular _______ deg
11. Specified Number of Cycles ________________
12. Design Torsion: Moment ________________ N•mm or Twist Angle ____________________________ deg

13. Shell Material ______________________________ Bellows Material ________________________
14. Shell Thickness ______ mm Shell Corrosion Allowance: Internal ______ mm External ______ mm
15. Shell Radiography: None / Spot / Full
16. End Preparation: Square Cut __ Outside Bevel __ Inside Bevel __ Double Bevel __ (Describe in Line 24 if special)
17. Heat Exchanger Tube Length Between Inner Tubesheet Faces ______ mm

(07/25)

FORM UEB-1M SPECIFICATION SHEET FOR ASME SECTION VIII, DIVISION 1 PART UEB BELLOWS EXPANSION JOINTS (Cont'd)

18. Maximum Bellows Spring Rate: N Y - ____________________ N/mm
19. Internal Liner: N Y - Material ____________________
20. Drain Holes in Liner: N Y - Quantity/Size ____________________
21. Liner Flush With Shell I.D.: N Y - Telescoping Liner? N ____ Y____
22. External Cover: N Y - Material ____________________
23. Preproduction Approvals Required: N Y - Drawings / Bellows Calculations / Weld Procedures

24. Additional Requirements (e.g., bellows preset, ultrasonic inspection):

NOTE:

(1) For multiple movements, Design movements (line 10) can be replaced by operating movements, which should then be described under "Additional Requirements" (line 24). For each one of them, axial compression or axial extension, lateral deflection and angular rotation at each extremity of cycle, together with the specified number of cycles, should be indicated. When known, the order of occurrence of the movements should also be indicated.

(07/25)

(25)

PART UEJ
FLEXIBLE SHELL ELEMENT EXPANSION JOINTS

UEJ-1 GENERAL

(a) The rules in this Part cover the minimum requirements for design, fabrication, and inspection of flexible shell element expansion joints.

(1) Design requirements for flexible shell element expansion joints in Section VIII, Division 2, 4.20 shall be used in lieu of those previously listed in Mandatory Appendix 5. Table UEJ-1-1 lists the new locations for all requirements formerly located in this Division.

(2) The Division 1 design requirements listed in Table UEJ-1-2 shall be used in lieu of the corresponding design requirements referenced in Division 2, 4.20.

(3) When a Mandatory Appendix 5 paragraph, table, or figure is referenced, the applicable section of Division 2 shall be used in accordance with UG-16(a) and Mandatory Appendix 46.

(4) Requirements other than design requirements shall be in accordance with this Part.

(b) The rules of this Part do not address cyclic loading conditions; therefore, consideration of cyclic loading for flexible shell element expansion joints is not required unless it is specified for the vessel. The user or the user's designated agent is cautioned that the design of some pressure vessels containing expansion joints (especially expansion joints with corners) may be governed by cyclic loading. It is recommended that cyclic conditions be included with the specification (see Nonmandatory Appendix KK).

UEJ-2 MATERIALS

Materials for pressure-retaining components shall conform to the requirements of UG-4.

UEJ-3 FABRICATION

(a) The flexible element is the flanged-only head, the flanged-and-flued head, the annular plate, or the flued-only head, as appropriate to the expansion joint configuration per Figure UEJ-3-1. The flexible element may be fabricated from a single plate (without welds) or from multiple plates or shapes welded together. When multiple plates or shapes are used to fabricate the flexible element, the following requirements apply:

(1) Welds shall be butt-type full penetration welds, Type (1) of Table UW-12.

(2) Welds shall be ground flush and smooth on both sides. For flexible elements to be formed, this shall be done prior to forming.

Table UEJ-1-1
Paragraph and Sentence Cross-Reference List

2023 Division 1 Paragraph, Topic	Division 2
5-1(a), Design rules	4.20.1(a) and 4.20.3(a)
5-1(b), Primary stress	4.20.3(d)
5-1(c), Movements	4.20.3(e)
5-1(e), Mechanical properties	4.20.3(f)
5-1(f), Uncommon designs	4.20.1(b)
5-2 (sentence 2), Carbon and low alloy steel minimum thickness	4.20.2(a)
5-2 (sentence 3), High alloy steel minimum thickness	4.20.2(b)
5-3(a), Stress limit	4.20.5(a) through 4.20.5(d)
5-3(b), Calculations	4.20.5(e)
5-3(c), Knuckle radius	4.20.2(c)
5-3(d), Spring rate	4.20.5(f)
5-3(e), Thinning of elements	4.20.3(c)
5-3(f), Outer shell element	4.20.2(d)
5-4(c) (last sentence), Nozzles or other attachments	4.20.2(e)

Table UEJ-1-2
Division 2 Cross-Reference List to Division 1 Requirements

Topic	Division 2 Paragraph	Division 2 Reference	Division 1
Typical flexible shell element expansion joints	4.20.1(a), 4.20.2(c), and 4.20.2(d)	Figure 4.20.1	Figure 5-1
Uncommon designs	4.20.1(b)	4.1.1.2	U-2(g)
Minimum thickness	4.20.2(b)	4.1.2	UG-16
Cylindrical shells	4.20.2(d)	4.3.3	UG-27
Primary stress	4.20.3(d)	4.1.6.1	UG-23(c)

GENERAL NOTE: As an example, when applying 4.20.1(b), substitute reference to 4.1.1.2 with reference to U-2(g).

(b) The circumferential weld attaching the flexible element to the shell, mating flexible element, or outer shell element, as appropriate to the expansion joint configuration per Figure UEJ-3-1, shall be as follows:

(1) Butt joints shall be full penetration welds, Type (1) of Table UW-12.

(2) Corner joints shall be full penetration welds with a covering fillet and no backing strip. The covering fillet shall have a throat at least equal to the lesser of 0.7 times the thickness of the thinner of the elements joined, or $^1/_4$ in. (6 mm). Note that a fatigue evaluation may require a larger weld. It is permitted for the corner weld to penetrate through either of the elements being joined.

(c) Nozzles, backing strips, clips, or other attachments shall not be located in highly stressed areas of the expansion joint, i.e., inner torus, annular plate, and outer torus. As an exception, a thin cylindrical liner, having approximately the shell inside diameter, may be attached to an inner torus or an annular plate inner corner. A liner is considered thin when its thickness is no more than $t/3$; however, it need not be thinner than $^1/_{16}$ in. (1.6 mm). This liner shall be attached to only one side. The weld attaching the liner shall have a maximum dimension (groove depth or either fillet leg) no larger than the liner thickness.

(d) The welds within the shell courses adjacent to flexible elements shall be full penetration butt welds, Type (1) of Table UW-12, for a distance of $2.5\sqrt{Rt}$, where R is R_a or R_b, and t is the thickness of the shell or outer shell element, as applicable.

(e) Alignment tolerances of the completed expansion joint attached to the shell shall meet the tolerances specified by UW-33.

UEJ-4 INSPECTION AND TESTS

(a) Expansion joint flexible elements shall be visually examined and found free of unacceptable surface conditions, such as notches, crevices, and weld spatter, which may serve as points of local stress concentration. Suspect surface areas shall be further examined by the magnetic particle or liquid penetrant method in accordance with Mandatory Appendix 6 or Mandatory Appendix 8.

(b) Welds within the flexible element shall be 100% examined in accordance with UW-51. These welds shall be examined 100% on both sides by the magnetic particle or liquid penetrant method in accordance with Mandatory Appendix 6 or Mandatory Appendix 8. For flexible elements to be formed, this surface inspection shall be after forming.

(c) The circumferential welds attaching the flexible element to the shell, mating flexible element, or outer shell element, as appropriate to the expansion joint configuration per Figure UEJ-3-1, shall be examined 100% on both sides, where accessible, by the magnetic particle or liquid penetrant method in accordance with Mandatory Appendix 6 or Mandatory Appendix 8. The accessibility of welds shall be subject to the acceptance of the Inspector.

(d) The completed expansion joint shall be pressure tested in accordance with UG-99 or UG-100. The pressure testing may be performed as a part of the final vessel pressure test, provided the joint is accessible for inspection during pressure testing.

(e) Expansion joint restraining elements shall also be pressure tested in accordance with UG-99 or UG-100 as a part of the initial expansion joint pressure test or as a part of the final vessel pressure test after installation of the joint.

(f) In addition to inspecting the expansion joint for leaks and structural integrity during the pressure test, expansion joints shall be inspected before, during, and after the pressure test for visible permanent distortion.

UEJ-5 MARKING AND REPORTS

The expansion joint Manufacturer, whether the vessel Manufacturer or a parts Manufacturer, shall have a valid ASME Code U Certificate of Authorization and shall complete the appropriate Data Report in accordance with UG-120.

(a) The Manufacturer responsible for the expansion joint design shall include the following additional data and statements on the appropriate Data Report:

(1) uncorroded and corroded spring rate

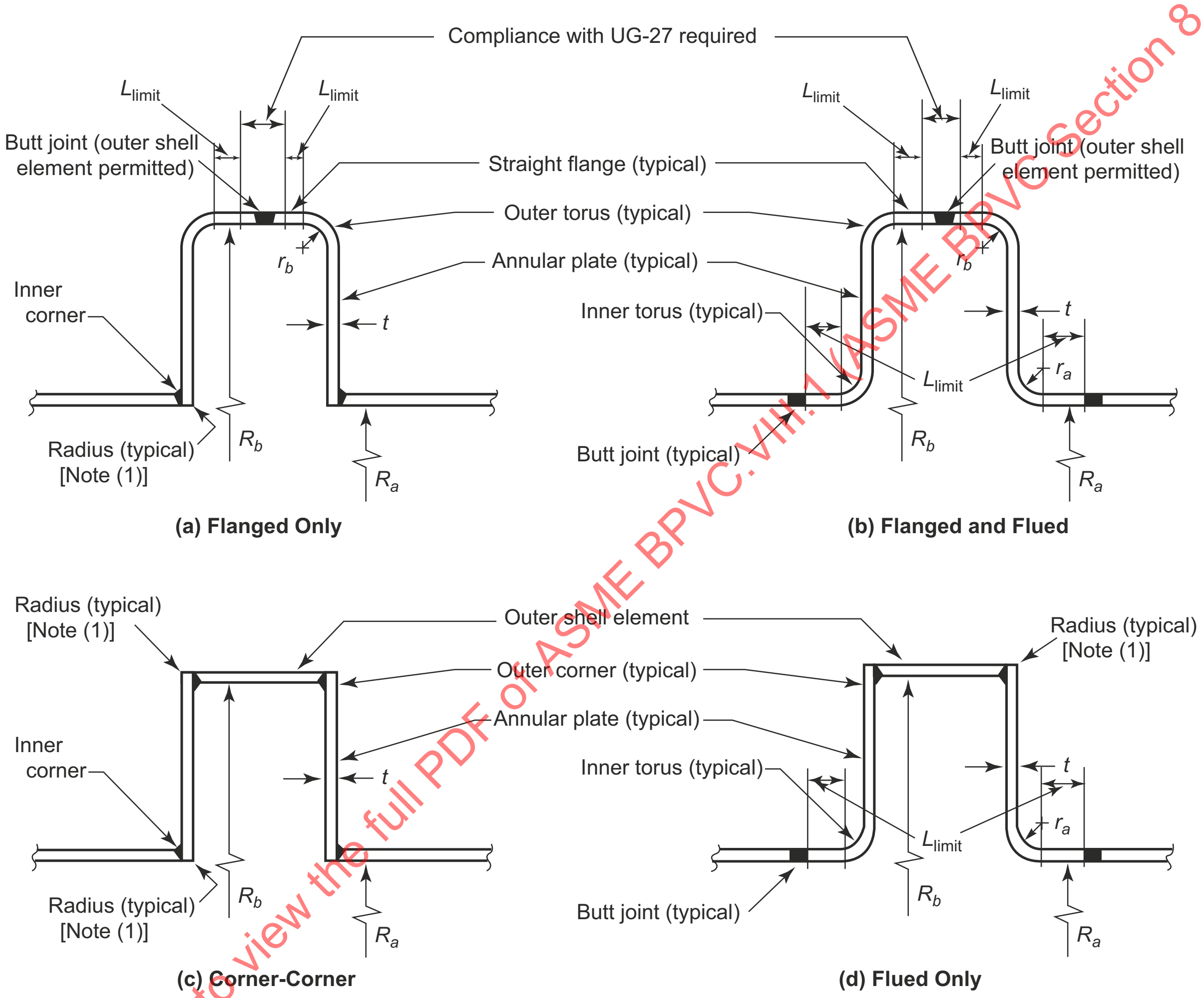
(2) axial movement (+ and −) and associated loading condition, if applicable

(3) that the expansion joint has been constructed to the rules of this Part

(b) A parts Manufacturer shall identify the vessel for which the expansion joint is intended on the Partial Data Report.

(c) Markings shall not be stamped on the flexible elements of the expansion joint.

Figure UEJ-3-1
Typical Flexible Shell Element Expansion Joints



Legend:

L_{limit} = maximum length where the requirements of UG-27 are not mandatory
= $^1/_2$SQRT(R_{tf})

R = uncorroded inside radius of expansion joint straight flange at the point of consideration
= R_a or R_b

t = thickness of expansion joint flexible element

t_f = uncorroded thickness of expansion joint straight flange

GENERAL NOTE: $r_a, r_b \geq 3t$.

NOTE:
(1) Where the term "Radius" appears, provide a $^1/_8$ in. (3 mm) minimum blend radius.

(25)

PART UGL ALTERNATIVE REQUIREMENTS FOR GLASS-LINED VESSELS

UGL-1 SCOPE

The rules of this Part cover acceptable alternative requirements that are applicable to glass-lined (enameled-lined) vessels. All applicable requirements in this Division are mandatory except as modified herein.

UGL-2 PERMISSIBLE OUT-OF-ROUNDNESS OF CYLINDRICAL SHELLS UNDER INTERNAL PRESSURE

If the out-of-roundness of a glass lined cylindrical vessel exceeds the limits in UG-80(a)(1), UG-80(a)(2), or in both, and the condition cannot be corrected, the maximum allowable working pressure may be calculated as follows:

(a) The out-of-roundness, as determined by the maximum difference between any two diameters for any cross section, shall not exceed 3%.

(b) The shell shall be certified for a lower internal pressure by the following formula:

$$\text{Reduced pressure } P' = P\left[\frac{1.25}{\frac{S_b}{S} + 1}\right]$$

and in which

$$S_b = \frac{1.5PR_1t(D_1 - D_2)}{t^3 + 3\frac{P}{E}R_1R_a^{\,2}}$$

where

D_1 *and* D_2 = the inside diameters, maximum and minimum, respectively, as measured for the critical section, and for one additional section in each direction therefrom at a distance not exceeding $0.2D_2$. The average of the three readings for D_1 and D_2, respectively, shall be inserted in the formula.

E = modulus of elasticity at design temperature

P = maximum allowable working pressure for shell meeting the requirements of UG-80(a)(1)

NOTE: Use $P' = P$ when $S_b \le 0.25S$

P' = reduced maximum allowable working pressure to be stamped on the nameplate of the vessel and shown on the Manufacturer's Data Report

R_1 = average inside radius at critical section
= $\frac{1}{4}(D_1 + D_2)$

R_a = average radius to middle of shell wall at critical section
= $\frac{1}{4}(D_1 + D_2) + t/2$

S = design stress value at metal service temperature

S_b = bending stress at metal service temperature

t = nominal thickness of vessel shell

UGL-3 PERMISSIBLE TOLERANCE FOR HEMISPHERICAL OR 2:1 ELLIPSOIDAL HEADS

If a hemispherical or 2:1 ellipsoidal head exceeds the tolerance limits in UG-81(a) and the condition cannot be corrected, the head may be used providing the following requirements are met:

(a) The inner surface of the head shall not deviate outside the specified shape by more than 3% of D nor inside the specified shape by more than 3% of D, where D is the nominal inside diameter of the vessel shell at the point of attachment. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt.

(b) The provisions of UG-81(c), UG-81(d), and UG-81(e) shall be met. UG-81(b) shall be met as regards the remaining spherical portions of the head.

(c) Deviations that exceed the limits in UG-81(a) shall be outside of any areas used for reinforcing of openings.

(d) A comparative analysis shall be made between the distorted shape and the undistorted shape to demonstrate that the design margins of the Code for internal pressure and, as appropriate, external pressure have been met [see U-2(g)].

UGL-4 HYDROSTATIC TEST

(a) The hydrostatic test pressure for glass-lined vessels shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the vessel; the hydrostatic test pressure for jackets of glass-lined vessels shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the jacket.

(b) Vessels, except those in lethal service, may be painted or glass lined internally prior to the pressure test. However, the user is cautioned that such painting/coating/lining may mask leaks that would otherwise be detected during the pressure test.

UGL-5 HEAT TREATMENT OF TEST SPECIMENS

(a) Except when impact testing per UCS-66 is required, and in lieu of the requirements of UCS-85, the plate, forging, pipe, and strip steels used in the production of glass-lined vessels may be represented by test specimens that meet the following requirements:

(1) the test specimens shall be heat treated two times, first to a temperature of 1,675°F ± 25°F (915°C ± 15°C), and then to a temperature that is nominally equal to the last (lowest) temperature of the glassing cycle. The minimum holding time for each heat treatment shall be $^1/_2$ hr/in. (1 min/mm) of thickness;

(2) the materials shall be limited to SA-106, SA-285, SA-414, SA-516, and SA-836; and

(3) the multiple temperature cycles used in the glassing operation shall be within the range of 1,450°F to 1,700°F (790°C to 925°C), with at least one cycle being above the upper transformation temperature of the material. The vessel is to be held at temperature approximately $^1/_2$ hr/in. ($^1/_2$ hr/25 mm) of thickness, and still-air-cooled to ambient.

(b) SA-106, SA-285, SA-414 Grades A and B, and SA-516 materials used in the production of glass-lined vessels may be exempt from the simulated test requirements of UCS-85 when the following requirements are met:

(1) the requirements of (a)(3) above;

(2) the carbon content of the materials shall not exceed 0.25% by heat analysis;

(3) the tensile strength and yield strength of the material, as represented by mill test specimens, shall be at least 10% higher than the minimum specified by the material specification;

(4) impact testing per UCS-66 is not required.

UGL-6 LOW TEMPERATURE OPERATION

Materials used in the fabrication of glass lined vessels shall follow the impact testing requirements or exemptions as defined within this Division with the exceptions listed below.

(a) SA-285 Grade C, for glass lined vessels, may be assigned to Curve B in Figure UCS-66 (Figure UCS-66M) under the following conditions:

(1) the maximum carbon content limit is 0.18%; and

(2) the glass operation shall be per UGL-5(a)(3).

(b) Stainless steel vessels fabricated from SA-240 316L plate, SA-182 F316L forgings, SA-312 TP316L pipe, and SA-213 TP316L tubing may be exempted from production impact tests per UHA-51, provided the following conditions are met:

(1) The Welding Procedure Qualification shall include impact tests in accordance with UHA-51(b). Each heat or lot of consumable welding electrodes shall be so tested. The test specimens shall be subjected to the glass lined 316L stainless steel vessel glassing cycle temperature, time, and cooling rates, and a number of cycles that is equal to or greater than that of the production vessels.

(2) The impact testing shall be done at a temperature not warmer than the MDMT of the vessels. The MDMT of the vessels shall be no colder than −155°F (−104°C).

(3) The multiple temperature cycles used in the glassing operation shall be within the range of 1,400°F to 1,700°F (760°C to 927°C). The vessel is to be held at temperature approximately $^1/_2$ hr/in. of thickness (0.20 hr/cm of thickness) per cycle, and still-air-cooled (nonquench) to ambient.

(4) As an alternative to (1) through (3) above, impact testing is not required when the coincident ratio of design stress[56] in tension to allowable tensile stress is less than 0.35, provided that the welding electrodes are certified to SFA-5.4 Grade 316L-15 with a ferrite number not to exceed 3, and provided that the MDMT of the vessels is no colder than −200°F (−129°C).

UGL-7 POSTWELD HEAT TREATMENT

The heat treatment provided in the temperature cycle for the glassing operation may be used in lieu of the postweld heat treatment requirements of UW-40 and UCS-56. The weld qualification test specimens required by UW-28 and Section IX shall be heat treated per UGL-5(a)(1). Inner vessels which are so heat treated need not be again postweld heat treated after the attachment to the jacket, if the joining welds do not require postweld heat treatment.

UGL-8 DATA REPORTS

When all the requirements of this Division, as modified by the alternative requirements of this Part, have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance With Part UGL, Alternative Requirements for Glass-Lined Vessels."

(25)
PART UHX
RULES FOR SHELL-AND-TUBE HEAT EXCHANGERS

(25) UHX-1 GENERAL

(a) The rules in Part UHX cover the minimum requirements for design, fabrication, and inspection of shell-and tube heat exchangers.

(1) Design requirements for shell-and-tube heat exchangers in Section VIII, Division 2, Part 4.18 shall be used in lieu of those previously listed in Part UHX.

(2) The Section VIII, Division 1 design requirements listed in Table UHX-1-1 shall be used in lieu of the corresponding Section VIII, Division 2 design requirements referenced in Part 4.18.

(3) When Part UHX section, paragraph, table, or graph is referenced, the applicable section of Division 2 shall be used in accordance with UG-16 and Mandatory Appendix 46, except as indicated in Table UHX-1-1.

(4) Except for the tubesheet, the design of all the elements in the shell-and-tube heat exchanger components shall be in accordance with the applicable rules of Subsections A and D, and the Mandatory Appendices.

(5) For nozzles adjacent to integral tubesheets [see Division 2, 4.18.3(h)], determine d in accordance with UG-40 in lieu of using the nomenclature for d from Division 2, 4.5.18.

(6) Conical sections of kettle heat exchangers shall meet the requirements of Mandatory Appendix 1 with the following adjustments:

(-a) Replace f_1 and f_2 in 1-5 with X_L and X_S, respectively, from Division 2, 4.18.8.9.2(g).

(-b) Replace f_1 and f_2 in 1-8 with $-X_L$ and $-X_S$, respectively, from Division 2, 4.18.8.9.2(g).

(7) Requirements other than design shall be in accordance with this Division.

(b) The rules in Part UHX cover the common types of shell-and-tube heat exchangers and their elements but are not intended to limit the configurations or details to those illustrated or otherwise described herein. Designs that differ from those covered in this Part shall be in accordance with U-2(g) in lieu of 4.1.1.2 referenced in 4.18.1(b).

(c) Design requirements for bellow expansion joints in Section VIII, Division 2, Part 4.19 are valid for design temperatures up to the temperatures shown in Table 26-1.2. The effects of time-dependent behavior above these temperatures (creep and creep–fatigue interaction) shall be considered in accordance with U-2(g).

UHX-2 MATERIALS AND METHODS OF FABRICATION (25)

Materials and methods of fabrication of heat exchangers shall be in accordance with Subsections A, B, C, and D.

UHX-18 PRESSURE TEST REQUIREMENTS

(a) The shell side and the tube side of the heat exchanger shall be subjected to a pressure test in accordance with UG-99 or UG-100.

(b) Shipping bars on bellows expansion joints may be required to maintain assembly length during shipment and vessel fabrication. Shipping bars shall not be engaged or otherwise provide any restraint of the expansion joint during vessel pressure testing and operation [see Division 2, 4.19.3.1(c) and 4.19.3.1(d)].

UHX-19 HEAT EXCHANGER MARKING AND REPORTS

UHX-19.1 Required Marking

The marking of heat exchangers shall be in accordance with UG-116 using the specific requirements of UG-116(j) for combination units (multi-chamber vessels). When the markings are grouped in one location in accordance with requirements of UG-116(j)(1) and abbreviations for each chamber are used, they shall be as follows:

(a) For markings in accordance with UG-116(a)(3) and UG-116(a)(4), the chambers shall be abbreviated as:

(1) SHELL for shell side

(2) TUBES for tube side

This abbreviation shall precede the appropriate design data. For example, use:

(3) SHELL FV&300 psi (FV&2 000 kPa) at 500°F (260°C) for the shell side maximum allowable working pressure

(4) TUBES 150 psi (1 000 kPa) at 350°F (175°C) for the tube side maximum allowable working pressure

(b) When the markings in accordance with UG-116(b)(1), UG-116(c), UG-116(e) and UG-116(f) are different for each chamber, the chambers shall be abbreviated as:

(1) S for shell side

(2) T for tube side

This abbreviation shall follow the appropriate letter designation and shall be separated by a hyphen. For example, use:

(3) L-T for lethal service tube side

(25)

Table UHX-1-1
Reference Paragraph Cross-Reference List

Topic	Division 2	Division 1
Jacketed vessels	4.11	Part UJV
Bolted flange connections	4.16	Mandatory Appendix 2
Bellows expansion joints	4.19	Part UEB
Flexible shell element expansion joints	4.20	Part UEJ
Tube-to-tubesheet joint strength	4.21	UW-20
Cone-to-cylinder junction under internal pressure	4.3.11, 4.3.12	1-5 [see UHX-1(a)(5)(-a)]
Cone-to-cylinder junction under external pressure	4.4.13, 4.4.14	1-8 [see UHX-1(a)(5)(-b)]
Flanges and pipe fittings	4.1.11	UG-44(a)
Tubesheets without a bolting flange	Table 4.2.6	Figure UW-13.2, sketches (a) through (g)
Tubesheets with a bolting flange	Table 4.2.8	Figure UW-13.2, sketches (h) through (l)
Tubesheets with butt weld hubs	Table 4.2.7	Figure UW-13.3
Allowable compressive stress	4.4.12.2 [Note (1)]	UG-23(b)

NOTE:
(1) Required by 46-2(a)(1).

(4) RT 1-S for full radiography on the shell side

UHX-19.2 Supplemental Marking

A supplemental tag or marking shall be supplied on the heat exchanger to caution the user if there are any restrictions on the design, testing, or operation of the heat exchanger. The marking shall meet the requirements of UG-118 or UG-119, except that height of the characters for the caution required by UHX-19.2.2 shall be at least $^1/_8$ in. (3 mm) high. Supplemental marking shall be required for, but not limited to, the following:

UHX-19.2.1 Common Elements. Shell-and-tube heat exchangers are combination units as defined in UG-19(a) and the tubes and tubesheets are common elements. The following marking is required when the common elements are designed for conditions less severe than the design conditions for which its adjacent chambers are stamped.

(a) Differential Pressure Design. When common elements such as tubes and tubesheets are designed for a differential design pressure, the heat exchanger shall be marked "Differential Design" in addition to meeting all the requirements of UG-19(a)(2) [see UG-116(j)]. If the tubes and tubesheets are designed for a differential pressure of 150 psi, an example of the marking would be

DIFFERENTIAL DESIGN: TUBES
& TUBESHEETS 150 psi

(b) Mean Metal Temperature Design. When common elements such as tubes and tubesheets are designed for a maximum mean metal design temperature that is less than the maximum of the shell side and tube side design temperatures, the heat exchanger shall be marked "Max Mean Metal Temp" in addition to meeting all the requirements of UG-19(a)(3) [see UG-116(j)]. If the tubes are designed for a maximum mean metal temperature of 400°F, an example of the marking would be

MAX MEAN METAL TEMP: TUBES 400°F

UHX-19.2.2 Fixed Tubesheet Heat Exchangers. Fixed tubesheet heat exchangers shall be marked with the following caution:

CAUTION: The heat exchanger design has been evaluated for the range of conditions listed on Nonmandatory Appendix W, Form U-5 of the MDR. It shall be reevaluated for conditions outside this range before being operated at them.

UHX-19.3 Manufacturer's Data Reports

UHX-19.3.1 Common Elements. When common elements such as tubes and tubesheets are designed for a differential pressure, or a mean metal temperature, or both, that is less severe than the design conditions for which its adjacent chambers are stamped, the data for each common element that differs from the data for the corresponding chamber shall be indicated as required by UG-19(a) and UG-120(b) in the "Remarks" section of the Manufacturer's Data Report.

UHX-19.3.2 Fixed Tubesheet Heat Exchangers. For each design and operating condition, the following information shall be indicated on Nonmandatory Appendix W, Form U-5 of the Manufacturer's Data Report Supplementary Sheet for Shell-and-Tube Heat Exchangers. The operating conditions may be combined on this form where they are bounded by the operating pressure range, maximum metal temperatures, and axial differential thermal expansion range.

(a) Name of Condition. The first condition shown shall be the design condition. If there is more than one design condition or a differential pressure design condition, multiple lines may be used. Each different operating condition or range of operating conditions shall be listed.

(b) Design/Operating Pressure Ranges. Range of shell side and tube side pressures for each condition shall be listed.

(c) Design/Operating Metal Temperatures. For each condition, the temperature at which the allowable stress was taken for the shell, channel, tube, and tubesheet shall be listed. Any metal temperature between the MDMT and the listed temperature is permitted, provided the resulting axial differential thermal expansion is within the listed range.

(d) Axial Differential Thermal Expansion Range. The minimum and maximum axial differential thermal expansion for each operating condition shall be listed. If the minimum value is positive, zero shall be used for the minimum value. If the maximum value is negative, zero shall be used for the maximum value. Within the listed range of operating temperature and pressure, any combination of shell and tube axial mean metal temperatures is permitted, provided the resulting axial differential thermal expansion is within the listed range.

UHX-20 EXAMPLES

See UG-16(c).

PART UIF
INTEGRALLY FORGED VESSELS

(25)

UIF-1 SCOPE

This Part covers the minimum requirements for the design, fabrication, and inspection of special integrally forged pressure vessels having a higher allowable stress value than that for vessels under Part UF, provided additional requirements specified in this Part are met.

UIF-2 MATERIAL

The forging material shall comply with SA-372 Grade A; Grade B; Grade C; Grade D; Grade E, Class 55, 65, or 70; Grade F, Class 55, 65, or 70; Grade G, Class 55, 65, or 70; Grade H, Class 55, 65, or 70; Grade J, Class 55, 65, or 70; Grade L; Grade M, Class A or B; Grade N, Class 100 or 120; or Grade P, Class 100 or 120.

UIF-3 DESIGN

(a) A maximum allowable stress value of one-third the minimum tensile strength specified in the material specification (Section II) for the grade shall be used.

(b) The maximum inside diameter of the shell shall not exceed 24 in. (600 mm).

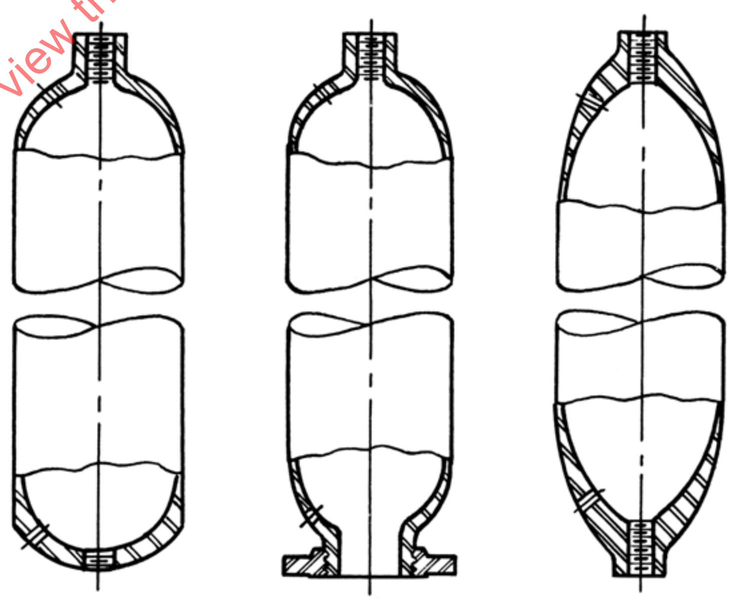
(c) The design metal temperatures shall be as given in UG-20, except the maximum temperature shall not exceed 200°F (95°C). All other requirements of UG-20 shall be met.

(d) The vessel shall be of streamlined design, as shown in Figure UIF-1, with the following features:

(1) The shell portion shall have no stress raisers, such as openings, welded attachments, or stamping, except for identification stamping on the forging material prior to heat treatment.

(2) The integral heads shall be hot formed, concave to the pressure, and so shaped and thickened as to provide details of design and construction of the center openings which will be as safe as those provided by the rules of this Division; the center openings shall not exceed the lesser of 50% of the inside diameter of the vessel or NPS 3 (DN 80); other openings in the head shall not exceed NPS $^{3}/_{4}$ (DN 20); openings shall be placed at a point where the calculated membrane stress, without holes, is not more than one-sixth of the specified minimum tensile strength.

Figure UIF-1
Typical Sections of Special Seamless Vessels



(3) The vessel shall have no welding, except for seal welding of threaded connections performed either before or after heat treatment in accordance with UF-32.

UIF-4 HEAT TREATMENT

(a) The completed vessel, after all forging operations, shall be heat treated by one of the applicable methods outlined in SA-372.

(b) The tensile properties shall be determined by the testing method outlined in SA-372.

(c) When liquid quenched and tempered, each vessel shall be hardness tested as outlined in UF-31(b)(2).

(d) After heat treatment, the outside surface of each vessel, regardless of the type of heat treatment used, shall be subjected to the magnetic particle test or the liquid penetrant test as outlined in UF-31(b)(1).

UIF-5 MARKING

(a) The vessel shall be stamped on the thickened head portion with both the maximum allowable working pressure based on that for vessels under Part UF and also the maximum allowable working pressure based on a stress equal to one-third the specified minimum tensile strength. See UG-151(e).

(b) The words “Part UIF” shall be stamped following the latter pressure in (a) above.

UIF-6 DATA REPORTS

When all the requirements of this Division and the supplemental requirements of this Part have been met, the following notation shall be entered on the Manufacturer’s Data Report under "Remarks": “Constructed in Conformance with Part UIF, Integrally Forged Vessels.”

PART UIG REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF IMPERVIOUS GRAPHITE (25)

NONMANDATORY INTRODUCTION

(a) General. The use of impervious graphite for the manufacture of pressure vessels presents unique material considerations for design, fabrication, and testing. Metallic vessels, being made from materials that are normally ductile, are designed using well-established allowable stresses based on measured tensile and ductility properties. In contrast, the parts of impervious graphite vessels are relatively brittle, and the properties of the parts are dependent upon the fabrication process. It is the purpose of this Introduction to describe in a general way the criteria that were used in preparing this Part.

(b) Materials. Graphite is naturally porous, so it is either impregnated with resin or combined with a binder system to make it impervious to gases and liquids; therefore, only impervious graphite is suitable for construction of pressure vessels and components. However, the resin used for impregnation, or the binder system used to produce compound material, has a significant effect on the properties of the graphite. The impregnation cycle and resin type, or binder system and manufacturing process, may vary from manufacturer to manufacturer and may also vary for each grade of the impervious material the Manufacturer produces; therefore, the specified process should be tightly controlled to ensure that the material meets the specified properties.

Impervious graphite is made up of different combinations of graphite grades and impregnating agents or binder materials that are combined in a specified process to make a unique composite material (impregnated, compound, and unimpregnated graphite materials are often categorized into grades). Specifications exist for graphite, impregnating agents, and other binder materials; however, there are no published specifications for impervious graphite. Also, some grades of impervious graphite may be more suitable for certain applications (service conditions) than other grades. The impervious graphite manufacturing process is specified by the Manufacturer and is proprietary. The "specified process" is a listing of each step required to produce a specific grade of impervious graphite. It includes such items as the grade of graphite, resin or binder, vacuum, pressure, and any other steps needed to produce the desired grade of impervious graphite.

(c) Design. Adequacy of specific designs should be qualified by compliance with all applicable materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection rules contained in this Division.

(d) Modulus of Elasticity. The typical modulus of elasticity for impregnated graphite, 2.0×10^6 psi (14×10^3 MPa), is much lower than that of ferrous materials, which may be on the order of 30×10^6 psi (207×10^3 MPa). This low modulus characteristic requires careful consideration of vessel geometry in order to minimize bending and tensile stresses.

(e) Fatigue. Like metallic materials, the impervious graphite material, when stressed at sufficiently low levels, exhibits good fatigue life. While fatigue is not directly addressed by Part UIG, if service conditions warrant, the Manufacturer should take fatigue into consideration.

(f) Creep and Temperature Effects. Impervious graphite material is not subject to creep. The material has nearly constant tensile strength characteristics throughout the specified temperature range. Possible loss of strength at elevated temperatures is related to the maximum permissible temperature of the impregnation agent or binder system.

(g) Inspection. This Part incorporates the general philosophy of Section VIII, Division 1, regarding inspection during fabrication. Familiarity with impervious graphite production processes and the nature of vessel imperfections is required of the Authorized Inspector. Reliance is placed upon thorough monitoring of the Manufacturer's Quality Control Program, close visual inspection of vessels and vessel parts by both Manufacturing personnel and the Authorized Inspector, as well as acceptance testing where required by this Part.

GENERAL

UIG-1 SCOPE (25)

The rules in Part UIG are applicable to pressure vessels and vessel parts that are constructed of impervious graphite materials and shall be used in conjunction with the rules in this Division insofar as these requirements are applicable to graphite materials. Impervious graphite vessels may not be constructed under the rules of U-1(j) or UG-90.3(b).

UIG-2 EQUIPMENT AND SERVICE LIMITATIONS

(a) Impervious graphite pressure vessels covered by Part UIG are limited to the following:

(1) shell and tube heat exchangers
(2) bayonet heat exchangers
(3) cylindrical block heat exchangers
(4) rectangular block heat exchangers
(5) plate heat exchangers
(6) cylindrical vessels

(b) Impervious graphite pressure vessels have the following limitations:

(1) maximum external design pressure: 350 psi (2.4 MPa)
(2) maximum internal design pressure: 350 psi (2.4 MPa)
(3) minimum design temperature: −100°F (−73°C)
(4) maximum design temperature: 400°F (204°C)

(c) Metal parts used in conjunction with impervious graphite pressure vessels, including those for lethal service, shall be constructed in accordance with the requirements of this Division.

(25) UIG-3 TERMINOLOGY

batch: that quantity of material contained in a single impregnation cycle.

binder system: a combination of materials and processes used in the production of impervious compound graphite material.

cementing: the process of joining parts using graphite cement followed by a curing process.

certified materials: impregnated or compound graphite materials that have been manufactured, tested, and documented as described in this Part. Certified materials may be manufactured only by a Certificate Holder.

compound graphite material: graphite material mixed with a binder system and with a minimum graphite content of 50%, and that has a coefficient of permeability that is not more than the maximum allowable value per Table UIG-6-1.

graphite cement: mix of carbon or graphite powder and resin primarily used in the cementing process.

impregnated graphite material: graphite forms in which pores are filled with impregnation agents and that have a coefficient of permeability that is not more than the maximum allowable value per Table UIG-6-1

grade: material manufacturer's designation for a raw or certified material.

graphite part: any impervious graphite component certified by a Certificate Holder.

graphite pressure vessel: a pressure vessel constructed of certified materials.

graphitization: a solid-state transformation of carbon into graphite by means of heat treatment.

lot: the quantity of certified material produced within a 3-month period from a specific grade of graphite and resin or binder system that meets established specifications for material properties. Furthermore, the impregnation process must be controlled to a process specification. (See UIG-84.)

raw materials: include graphite materials, impregnation agents, and binder system components.

graphite material: a bonded granular carbon body whose matrix has been subjected to a temperature in excess of 4,350°F (2 400°C), and whose matrix is thermally stable below that temperature.

impregnation agent: material used to render carbon and graphite materials impervious.

MATERIALS

UIG-5 RAW MATERIAL CONTROL (25)

(a) Raw materials used in the manufacturing of the certified material shall be identified by its source and grade, and documented on the Certified Material Qualification (see Form CMQ) by the Certificate Holder.

(b) Graphite material and the impregnating agent or binder system materials used in the construction of graphite pressure vessels, and vessel parts shall be the same as the materials specified in the Certified Material Specification (CMS) (see UIG-77). Each of these materials shall be traceable in accordance with UIG-112(b).

UIG-6 CERTIFIED MATERIAL CONTROL (25)

(a) All material used in the construction of graphite pressure vessels shall be certified by the Manufacturer of the material to meet the properties in Table UIG-6 and all other requirements in Part UIG.

(b) The Manufacturer of certified material shall prepare a Certified Material Test Report (CMTR) that shall include the following, as a minimum (see UIG-84):

(1) Manufacturer's name
(2) lot number
(3) grade
(4) lot specific room temperature compressive strength values
(5) lot specific room temperature tensile strength values
(6) date tested
(7) tensile strength values at the maximum allowable material temperature
(8) compressive strength values at the maximum allowable material temperature

(c) The Manufacturer of certified material shall perform testing to meet the minimum properties in Table UIG-6-1 and test frequency for strength per UIG-84.

(25)

Table UIG-6-1
Required Properties of Certified Material

	Impregnated [Note (1)] Material	Compound [Note (2)] Material	Cement [Note (3)] Material
Minimum tensile strength at room temperature	2,000 psi (13.8 MPa)	1,500 psi (10.3 MPa)	1,500 psi (10.3 MPa)
Minimum compressive strength at room temperature	6,500 psi (45 MPa)	4,500 psi (31 MPa)	N/A [Note (4)]
Maximum coefficient of permeability	4.5×10^{-6} in.^{2}/sec (2.9×10^{-3} mm^2/s)	4.5×10^{-6} in.^{2}/sec (2.9×10^{-3} mm^2/s)	N/A [Note (4)]

NOTES:
(1) Resin-impregnated graphite.
(2) Resin-bonded graphite.
(3) Resin with graphite filler and catalyst.
(4) N/A = not applicable

(d) The Manufacturer shall additionally prepare a Certified Cement Specification (CCS) (see UIG-78). The cement material and cementing procedure (see UIG-79) shall be qualified. Tensile testing shall be performed per UIG-102.

(25) UIG-7 ADDITIONAL PROPERTIES

The modulus of elasticity tested per ASTM C747 and ASTM C769 is typically 2.0×10^6 psi (14×10^3 MPa), and the Poisson's ratio for impervious graphite is typically 0.15. The coefficient of thermal expansion for impervious graphite exhibits a typical range of 1.5 to 3.5×10^{-6} in./in.-°F (2.7 to 6.3×10^{-6} mm/mm-°C).

(25) UIG-8 TOLERANCES FOR IMPERVIOUS GRAPHITE TUBES

Extruded graphite tubes 3 in. O.D. and under shall meet the following tolerances:

(a) outside diameter: ±0.062 in. (1.5 mm)
(b) inside diameter: ±0.062 in. (1.5 mm)
(c) wall thickness variation: −0.062 in. (−1.5 mm)
(d) out-of-roundness: 0.04 in. (1.0 mm)
(e) bow: 0.70% of unit length

DESIGN

UIG-22 LOADINGS

The loadings described in UG-22 shall be considered in the design of graphite pressure vessels and vessel parts. Flexible joints (expansion joints/flexible bellows) should be used for all connections to graphite components to minimize loads on nozzles and other connections. The user shall make provisions for the reaction forces from pressure relief devices on graphite components.

UIG-23 MAXIMUM ALLOWABLE STRESS VALUES FOR CERTIFIED MATERIAL (25)

(a) The design factor to be used for graphite pressure vessel parts shall be not less than 6.0 except as stated in (c).

(b) The maximum allowable tensile stress value to be used in design shall be 80% of the determined value at the design temperature, divided by the design factor of 6.0 (7.0 for lethal service; see UIG-60).

(c) See below.

(1) The maximum allowable compressive stress value to be used in design shall be 80% of the determined value at the design temperature, divided by the design factor of 6.0 (7.0 for lethal service; see UIG-60).

(2) The maximum allowable compressive stress value to be used in design of graphite pressure vessel parts under the gasket of a flanged joint resulting from the design bolt load, W, for the operating condition and the gasket seating condition (see Mandatory Appendix 2) shall be limited to 30% of the determined compressive strength value at the design temperature.

(d) The design value for tensile and compressive stresses at the design temperature shall be calculated using the strength variation values from Form CMQ.

UIG-27 THICKNESS OF CYLINDRICAL SHELLS MADE OF CERTIFIED MATERIALS UNDER INTERNAL PRESSURE (25)

The minimum thickness or the maximum allowable working pressure (MAWP) of cylindrical shells, made of certified materials and subject to internal pressure, shall be calculated in accordance with the equations in UG-27 or Mandatory Appendix 1, as applicable, using a joint efficiency of E = 1.0. The minimum wall thickness shall be greater than or equal to the calculated minimum value.

(25) UIG-28 EXTERNAL PRESSURE

(a) Out-of-Roundness Less Than 0.5%

The maximum allowable external pressure shall not be greater than that calculated by the following formula when the out-of-roundness is less than or equal to 0.5%.

$$P_e = 5S_t\frac{t}{D}$$

where

D = nominal outside diameter
P_e = maximum allowable external pressure
S_t = maximum allowable tensile stress
t = nominal wall thickness

(b) Out-of-Roundness Greater Than 0.5%

The maximum allowable external pressure shall not exceed that calculated by the following formula when the out-of-roundness is greater than 0.5%.

$$P_e = 2S_c\frac{t}{D}\left[\frac{1}{1+\frac{1.5u\left(1-0.2\frac{D}{L}\right)D}{100t}}\right]$$

where

D = inside diameter of cylindrical shell
L = design length of a vessel or tube section between lines of support
S_c = allowable compressive stress per UIG-23(c)(1)
u = $2\frac{D_{i\,max} - D_{i\,min}}{D_{i\,max} + D_{i\,min}}$ 100, % out-of-roundness

(25) UIG-34 CALCULATING FLAT HEADS, COVERS, AND TUBESHEETS

The minimum thickness of flat heads and covers shall conform to the following requirements:

(a) The minimum required thickness of a graphite flat head or cover held in place by a bolted steel backing plate causing an edge moment shall be calculated by the following formula [see Figure UG-34, sketch (j)]:

$$t = G\sqrt{\frac{0.3P}{S_t} + \frac{1.9Wh_g}{S_tG^3}}$$

where

G = the diameter at the location of the gasket load reaction, as defined in this Division
h_g = gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction
P = design pressure
S_t = allowable tensile stress
t = minimum required thickness
W = total bolt load

(b) Design Procedure for Tubesheets

(1) Scope. This procedure describes how to design tubesheets for graphite shell and tube heat exchangers. These rules cover the design of tubesheets for heat exchangers that have one stationary tubesheet (fixed end) and one floating tubesheet (floating end) as shown in Figure UIG-34-1. Stationary tubesheets shall be as shown in Figure UIG-34-2, sketch (a) or sketch (b), and floating tubesheets shall be as shown in Figure UIG-34-3, sketch (a), sketch (b), or sketch (c).

(2) Conditions of Applicability.

(-a) There shall be no untubed lanes.

(-b) There shall be no pass partition grooves.

(-c) The tubes shall not be considered in the calculation of the ligament efficiency.

(-d) Tubesheet thickness to tube pitch ratio (h/p) shall be greater than or equal to 2.0.

(-e) Both tubesheets shall be certified material.

(-f) Tubesheets shall be flat and circular.

(-g) Tubesheets shall be uniformly perforated over a nominally circular area, in either equilateral triangular or square patterns.

(-h) Stationary and floating tubesheet thicknesses may be different, but each tubesheet shall be of uniform thickness, with the exception of gasket grooves or facing thicknesses.

(-i) Tube side and shell side pressures are assumed to be uniform.

(3) Nomenclature. The symbols described below are used for the design of graphite tubesheets.

A = outside diameter of tubesheet (or skirt for configuration d)
a_c = radial channel dimension
All configurations: $a_c = G_c/2$
a_o = equivalent radius of outer tube limit circle
a_s = radial shell dimension
configurations a and b: $a_s = G_s/2$
configurations c, d, and e: $a_s = A/2$
d = diameter of tube hole in tubesheet
D_o = equivalent diameter of outer tube limit circle [see Figure UIG-34-4, sketch (a)]
d_r = nominal diameter of spring rods
D_s = inside shell diameter
d_t = nominal outside diameter of tubes
E = modulus of elasticity for tubesheet material
E^* = effective modulus of elasticity of tubesheet in perforated region
E_r = modulus of elasticity for spring rod material
E_s = modulus of elasticity for shell material at T_s
$E_{s,w}$ = joint efficiency (longitudinal stress) for shell
E_t = modulus of elasticity for tube material
G_1 = midpoint of contact between the split shear ring and tubesheet

G_c = diameter of channel gasket load reaction (see Mandatory Appendix 2)
G_s = diameter of shell gasket load reaction (see Mandatory Appendix 2)
h = tubesheet thickness
J = ratio of spring rigidity, $K_J N_r$, to the effective axial rigidity of the shell and spring rods, K_{sr}
= 1.0 if there are no springs
k = constant accounting for the method of support for the unsupported tube span under consideration
= 0.6 for unsupported spans between two tubesheets
= 0.8 for unsupported spans between a tubesheet and a tube support
= 1.0 for unsupported spans between two tube supports
K_J = axial rigidity of spring or spring stack on each spring rod
K_r = axial rigidity of each spring rod
K_s = axial rigidity of shell
K_{sr} = effective axial rigidity of shell and spring rods
K_{srt} = ratio of effective axial rigidity of shell and spring rods to axial rigidity of tubes
K_t = axial rigidity of each tube
L = tube length between inner tubesheet faces
= $L_t - 2L_c$
ℓ = unsupported tube span under consideration
L_c = tube counter bore depth in tubesheet [see Figure UIG-34-4, sketch (b)]
L_r = effective length of spring rods (see Figure UIG-34-1)
L_s = effective shell length (see Figure UIG-34-1)
L_t = tube length
N_r = number of spring rods
N_t = number of tubes
p = tube pitch [see Figure UIG-34-4, sketch (a)]
P_e = effective pressure acting on tubesheet
P_s = shell side design or operating pressure, as applicable. For shell side vacuum, use a negative value for P_s.
$P_{sd,\max}$ = maximum shell side design pressure
$P_{sd,\min}$ = minimum shell side design pressure (negative if vacuum is specified, otherwise zero)
P_{sox} = shell side operating pressure for operating condition x (positive, negative, or zero operating pressure)
P_t = tube side design or operating pressure, as applicable. For tube side vacuum, use a negative value for P_t.
$P_{td,\max}$ = maximum tube side design pressure
$P_{td,\min}$ = minimum tube side design pressure (negative if vacuum is specified, otherwise zero)
P_{tox} = tube side operating pressure for operating condition x (positive, negative, or zero operating pressure)
r_o = radius to outermost tube hole center [see Figure UIG-34-4, sketch (a)]
S = allowable stress for tubesheet material at T
S_s = allowable stress for shell material at T_s
S_t = allowable tensile stress for tube material at T_t
S_{tc} = allowable compressive stress for tube material at T_t
T = tubesheet design temperature for the design condition or operating temperature for operating condition x, as applicable [see (4)(-b)]
T_a = ambient temperature
T_s = shell design temperature for the design condition or operating metal temperature for operating condition x, as applicable [see (4)(-b)]
t_s = shell thickness
$T_{s,m}$ = mean shell metal temperature along shell length
$T_{s,mx}$ = shell axial mean metal temperature for operating condition x, as applicable
T_t = tube design temperature for the design condition or operating temperature for operating condition x, as applicable [see (4)(-b)]
t_t = nominal tube wall thickness
$T_{t,m}$ = mean tube temperature along tube length
$T_{t,mx}$ = tube axial mean temperature for operating condition x, as applicable
W^* = tubesheet effective bolt load to be taken as $W_{\max}$ for all cases and configurations
x = 1, 2, 3, ..., n, integer denoting applicable operating condition under consideration (e.g., normal operation, start-up, shutdown, cleaning, upset)
$\alpha_{s,m}$ = mean coefficient of thermal expansion of shell material at $T_{s,m}$
$\alpha_{t,m}$ = mean coefficient of thermal expansion of tube material at $T_{t,m}$
δ_{spring} = initial compression of spring or spring stack
γ = axial differential thermal expansion between tubes and shell
μ = basic ligament efficiency for shear
ν = Poisson's ratio of tubesheet material
ν_s = Poisson's ratio of shell material
ν_t = Poisson's ratio of tube material
ν^* = effective Poisson's ratio in perforated region of tubesheet

(4) Design Considerations.

(-a) It is generally not possible to determine by observation the most severe condition of coincident pressure, temperature, and differential thermal expansion. Thus, it is necessary to evaluate all the anticipated loading conditions to ensure that the worst load combination has been considered in the design.

The user or the user's designated agent shall specify all the design and operating conditions that govern the design of the main components of the heat exchanger (i.e., tubesheets, tubes, shell). These shall include, but not be limited to, normal operating, start-up, shutdown, cleaning, and upset conditions.

For each of these conditions, the following loading cases shall be considered to determine the effective pressure, P_e, to be used in design formulas:

(-1) Design Loading Cases. Table UIG-34-1 provides the load combinations required to evaluate the heat exchanger for the design condition.

(-2) Operating Loading Cases. Table UIG-34-1 provides the load combinations required to evaluate the heat exchanger for each operating condition x. The design pressure shall be used for each operating loading case, unless the user or the user's designated agent provides an operating pressure (P_{sox}, P_{tox}) for each of the operating loading cases [see U-2(a)].

(-3) The designer shall take appropriate consideration of the stresses resulting from the pressure test required by UIG-99.

(-b) The elastic moduli, yield strengths, and allowable stresses shall be taken at the design temperatures for the design loading cases and may be taken at the operating temperature of the component under consideration for the operating condition x.

(-c) As the design procedure is iterative, a value h shall be assumed for the tubesheet thickness to calculate and check that the maximum stresses in the tubesheet, tubes, and shell are within the maximum permissible stress limits.

Because any increase of tubesheet thickness may lead to overstresses in the tubes or shell, a final check shall be performed, using in the equations the nominal thickness of the tubesheet, tubes, and shell, in both corroded and uncorroded conditions.

(-d) Both tubesheets shall be considered simply supported.

(-e) The design procedure shall be performed for the stationary tubesheet and the floating tubesheet. Since the edge configurations of the stationary and floating tubesheets are different, the data may be different for each set of calculations. However, the conditions of applicability given in (2) shall be maintained. For the stationary tubesheet, diameters A, G_s, and G_c shall be taken from Figure UIG-34-2. For the floating tubesheet, diameters A, G_c, and G_1 shall be taken from Figure UIG-34-3.

(-f) If no spring-loaded rods are used on the floating end, only Loading Cases 1 through 4 shall be considered; otherwise, all the loading cases shall be considered.

(5) Design Procedure. The procedure for the design of tubesheets for a graphite shell and tube heat exchanger is as follows:

Step 1. Determine D_o and μ.

$$D_o = 2r_o + d_t$$

$$\mu = \frac{p - d}{p}$$

Calculate a_o, ρ_s, and ρ_c for each tubesheet.

$$a_o = \frac{D_o}{2}$$

$$\rho_s = \frac{a_s}{a_o}$$

$$\rho_c = \frac{a_c}{a_o}$$

Calculate x_s and x_t.

$$x_s = 1 - N_t\left(\frac{d_t}{2a_o}\right)^2$$

$$x_t = 1 - N_t\left(\frac{d_t - 2t_t}{2a_o}\right)^2$$

Step 2. Calculate the shell axial stiffness, K_s; tube axial stiffness, K_t; spring rod axial stiffness, K_r; shell and spring rod pair axial stiffness, K_{sr}; and stiffness factors K_{srt} and J. If the exchanger does not have any spring-loaded rods on the floating end, J = 1, and proceed to Step 3.

$$K_s = \frac{\pi t_s(D_s + t_s)E_s}{L_s}$$

$$K_t = \frac{\pi t_t(d_t - t_t)E_t}{L}$$

$$K_r = \frac{\left(\frac{\pi d_r^2}{4}\right)E_r}{L_r}$$

$$K_{sr} = \frac{K_r N_r K_s}{K_r N_r + K_s}$$

$$K_{srt} = \frac{K_{sr}}{N_t K_t}$$

$$J = \frac{1}{1 + \frac{K_{sr}}{K_J N_r}}$$

Step 3. Using Table UIG-34-2 (equilateral triangular pattern) or Table UIG-34-3 (square pattern), determine E^*/E and ν^*.

$$E^*/E = \alpha_0 + \alpha_1\mu + \alpha_2\mu^2 + \alpha_3\mu^3 + \alpha_4\mu^4$$

$$\nu^* = \beta_0 + \beta_1\mu + \beta_2\mu^2 + \beta_3\mu^3 + \beta_4\mu^4$$

Calculate X_a for each tubesheet.

$$X_a = \left[24\left(1 - \nu^{*2}\right)N_t \frac{E_t t_t\left(d_t - t_t\right)a_o^2}{E^* L h^3}\right]^{\frac{1}{4}}$$

Use the calculated value of X_a and enter Table UIG-34-4 to determine Z_a, Z_d, Z_v, Z_w, and Z_m for each tubesheet.

Step 4. Calculate diameter ratio K and coefficient F for each tubesheet.

$$K = \frac{A}{D_o}$$

$$F = \frac{1 - \nu^*}{E^*}\left(E \ln K\right)$$

Calculate Φ, Q_1, Q_{Z1}, Q_{Z2}, and U for each tubesheet. If the exchanger does not have any spring-loaded rods on the floating end, do not calculate Q_{Z1}, Q_{Z2}, and U.

$$\Phi = \left(1 + \nu^*\right)F$$

$$Q_1 = \frac{\rho_s - 1 - \Phi Z_v}{1 + \Phi Z_m}$$

$$Q_{Z1} = \frac{\left(Z_d + Q_1 Z_w\right)X_a^4}{2}$$

$$Q_{Z2} = \frac{\left(Z_v + Q_1 Z_m\right)X_a^4}{2}$$

$$U = \frac{\left[Z_w + \left(\rho_s - 1\right)Z_m\right]X_a^4}{1 + \Phi Z_m}$$

Step 5. Calculate γ. On design cases 1 through 4, $\gamma = 0$. For operating cases 5 through 8, where the exchanger does not use any spring-loaded rods on the floating end, $\gamma = 0$; otherwise

$$\gamma = \left[\alpha_{t,m}\left(T_{t,m} - T_a\right) - \alpha_{s,m}\left(T_{s,m} - T_a\right)\right]L$$

Calculate $\omega_s{}^*$ and $\omega_c{}^*$ for each tubesheet.

$$\omega_s^* = a_o^2 \frac{\left(\rho_s^2 - 1\right)\left(\rho_s - 1\right)}{4}$$

$$\omega_c^* = a_o^2\left[\frac{\left(\rho_c^2 + 1\right)\left(\rho_c - 1\right)}{4} - \frac{\left(\rho_s - 1\right)}{2}\right]$$

Calculate γ_b.

Configurations a and b

$$\gamma_b = \frac{G_c - G_s}{D_o}$$

Configurations c, d, and e

$$\gamma_b = \frac{G_c - G_1}{D_o}$$

Step 6. For each loading case, calculate P_e for both tubesheets using either (a) or (b) below.

(a) If spring-loaded rods are used on the floating end, calculate P'_s, P'_t, P_γ, P_w, P_{rim}, P_{spring}, and effective pressure, P_e.

$$P_s' = \left[x_s + 2\left(1 - x_s\right)\nu_t + \frac{2}{K_{srt}}\left(\frac{D_s}{D_o}\right)^2 \nu_s - \frac{\rho_s^2 - 1}{J K_{srt}}\right]P_s$$

$$P_t' = \left[x_t + 2\left(1 - x_t\right)\nu_t + \frac{1}{J K_{srt}}\right]P_t$$

$$P_\gamma = \frac{N_t K_t}{\pi a_o^2}\gamma$$

$$P_w = -\frac{U}{a_o^2}\frac{\gamma_b}{2\pi}W^*$$

$$P_{rim} = -\frac{U}{a_o^2}\left(\omega_s^* P_s - \omega_c^* P_t\right)$$

$$P_{spring} = \frac{K_J N_r \delta_{spring}}{\pi a_o^2}$$

$$P_e = \frac{J K_{srt}}{1 + J K_{srt}\left[Q_{Z1} + \left(\rho_s - 1\right)Q_{Z2}\right]} \times \left(P_s' - P_t' + P_\gamma + P_w + P_{rim}\right) + P_{spring}$$

(b) If the exchanger does not have any spring-loaded rods on the floating end, use the following equation for P_e:

$$P_e = P_s\left[1 - \rho_s^2\right] - P_t$$

Step 7. For each loading case, calculate Q_2 for each tubesheet.

$$Q_2 = \frac{\left(\omega_s^* P_s - \omega_c^* P_t\right) + \frac{\gamma_b}{2\pi} W^*}{1 + \Phi Z_m}$$

For each loading case, calculate the maximum bending stress in each tubesheet in accordance with (a) or (b) below.

(a) When $P_e \neq 0$, calculate Q_3.

$$Q_3 = Q_1 + \frac{2Q_2}{P_e a_o^2}$$

For each loading case, determine coefficient F_m for each tubesheet from Table UIG-34-4 and then calculate the maximum bending stress, σ, for each tubesheet.

$$\sigma = \left(\frac{1.5F_m}{\mu}\right)\left(\frac{2a_o}{h}\right)^2 P_e$$

(b) When $P_e = 0$, calculate the maximum bending stress, σ, for each tubesheet.

$$\sigma = \frac{6Q_2}{\mu h^2}$$

If $|\sigma| \leq 1.5S$, the assumed tubesheet thickness is acceptable for bending. Otherwise, increase the assumed thickness, h, and return to Step 1.

Step 8. For each loading case, calculate the average shear stress, τ, in each tubesheet at the outer edge of the perforated region.

$$\tau = \frac{a_o}{2\mu h} P_e$$

If $|\tau| \leq 0.8S$, the assumed tubesheet thickness is acceptable for shear. Otherwise, increase the assumed tubesheet thickness, h, and return to Step 1.

Step 9. Perform this step for each loading case.

(a) Check the axial tube stress.

(1) For each loading case, determine coefficients $F_{t,\min}$ and $F_{t,\max}$ from Table UIG-34-5 and calculate the two extreme values of tube stress, $\sigma_{t,1}$ and $\sigma_{t,2}$. The values for $\sigma_{t,1}$ and $\sigma_{t,2}$ may be positive or negative.

(-a) When $P_e \neq 0$

$$\sigma_{t,1} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - P_e F_{t,\min}\right]$$

$$\sigma_{t,2} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - P_e F_{t,\max}\right]$$

(-b) When $P_e = 0$

$$\sigma_{t,1} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - \frac{2Q_2}{a_o^2} F_{t,\min}\right]$$

$$\sigma_{t,2} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - \frac{2Q_2}{a_o^2} F_{t,\max}\right]$$

(2) Determine $\sigma_{t,\max} = \max(\sigma_{t,1}, \sigma_{t,2})$. If $\sigma_{t,\max}$ is positive and $|\sigma_{t,\max}| > S_t$, reconsider the design and return to Step 1.

(3) Determine $\sigma_{t,\min} = \min(\sigma_{t,1}, \sigma_{t,2})$. If $\sigma_{t,\min}$ is negative and $|\sigma_{t,\min}| > S_{tc}$, reconsider the design and return to Step 1.

(b) Check the tubes for buckling. If $\sigma_{t,\min}$ is positive, skip this step and proceed to Step 10.

(1) Calculate the largest equivalent unsupported buckling length of the tube, ℓ_t, considering the unsupported tube spans, ℓ, and their corresponding method of support, k.

$$\ell_t = k\ell$$

(2) Calculate r_t and F_t.

$$r_t = \frac{\sqrt{d_t^2 + \left(d_t - 2t_t\right)^2}}{4}$$

$$F_t = \frac{\ell_t}{r_t}$$

(3) Determine the design factor, F_s, in accordance with (-a) or (-b) below.

(-a) When $P_e \neq 0$

$$F_s = \max\left\{\left[3.25 - 0.25\left(Z_d + Q_3 Z_w\right)X_a^4\right], \left[1.25\right]\right\}$$

F_s need not be taken as greater than 2.0.

(-b) When $P_e = 0$, $F_s = 1.25$.

(4) Determine the maximum permissible buckling stress limit, S_{tb}, for the tubes.

$$S_{tb} = \min\left\{\left[\frac{1}{F_s}\frac{\pi^2 E_t}{F_t^2}\right], \left[S_{tc}\right]\right\}$$

(5) If $|\sigma_{t,\min}| > S_{tb}$, reconsider the design and return to Step 1. If $|\sigma_{t,\min}| \leq S_{tb}$, the tube design is acceptable. Proceed to Step 10.

Step 10. If spring-loaded rods are used on the floating end, perform this step.

Calculate the axial membrane stress, $\sigma_{s,m}$, in each different shell section.

$$\sigma_{s,m} = \frac{a_o^2}{t_s(D_s + t_s)}\left[P_e + \left(\rho_s^2 - 1\right)\left(P_s - P_t\right)\right] + \frac{a_s^2}{t_s(D_s + t_s)}P_t$$

For all cases, if $|\sigma_{s,m}| > S_s E_{s,w}$, reconsider the design and return to Step 1.

If $\sigma_{s,m}$ is negative, that indicates complete spring relaxation. Reconsider the spring design and return to Step 1.

If $\sigma_{s,m}$ is positive, the shell design is acceptable and the design procedure is complete.

Figure UIG-34-1
Typical Graphite Shell and Tube Heat Exchanger

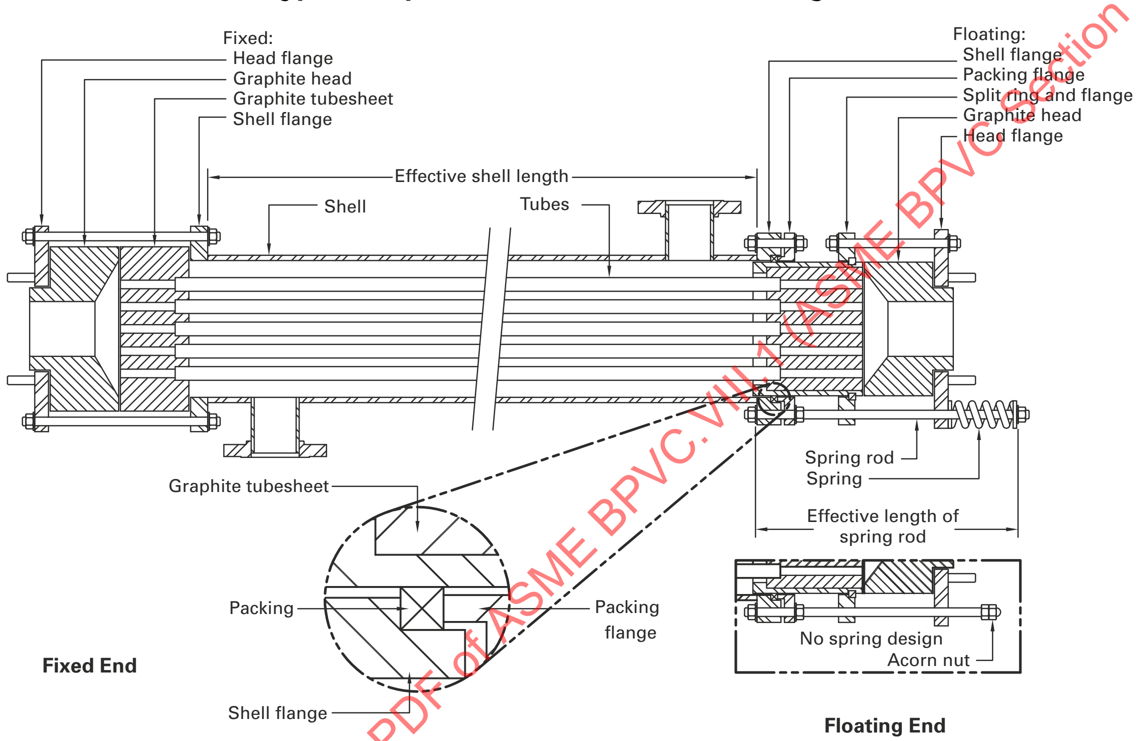
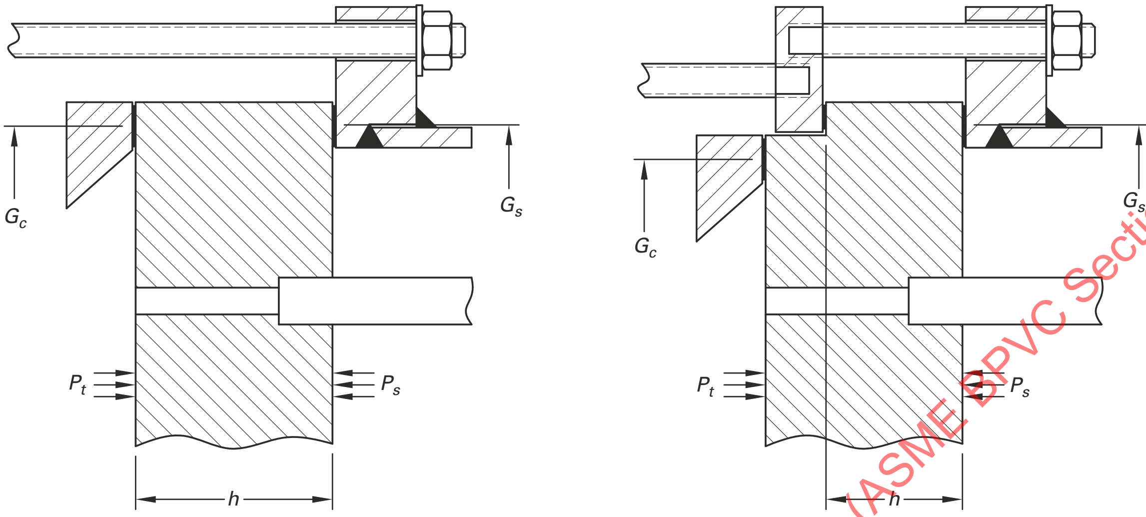


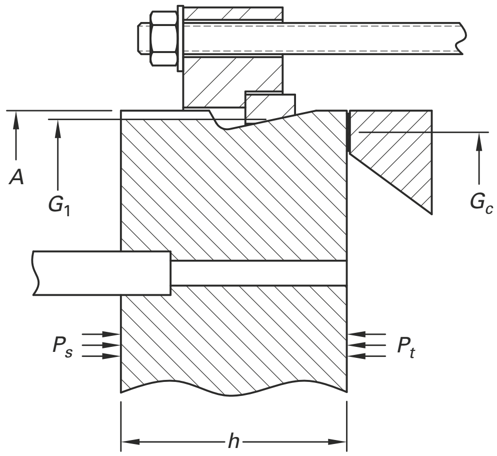
Figure UIG-34-2
Fixed Tubesheet Configurations



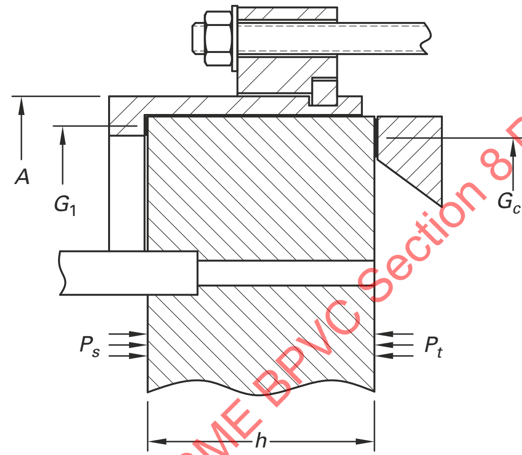
(a) Configuration a:
Tubesheet Gasketed With Shell and Head

(b) Configuration b:
Tubesheet Gasketed With Shell and Head, With Assembly Flange

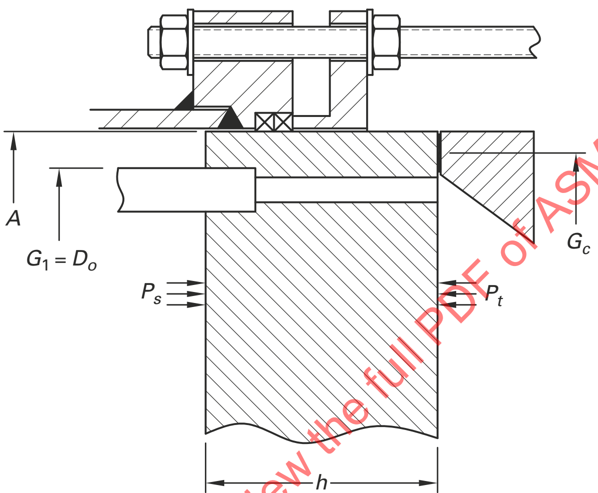
Figure UIG-34-3
Floating Tubesheet Configurations



(a) Configuration c:
Grooved Tubesheet With Split Ring
(With or Without Springs)



(b) Configuration d:
Tubesheet With Skirt and Split Ring
(With or Without Springs)



(c) Configuration e:
Fully Spring-Loaded Tubesheet Without Split Ring

(25)

Table UIG-34-1

Design Loading Case	Shell Side Design Pressure, P_s	Tube Side Design Pressure, P_t	Operating Loading Case	Shell Side Design Pressure, P_s	Tube Side Design Pressure, P_t	Axial Mean Temperature: Shell, $T_{s,m}$	Axial Mean Temperature: Tubes, $T_{t,m}$
1	$P_{sd,\min}$	$P_{td,\max}$	5	$P_{sox,\min}$	$P_{tox,\max}$	$T_{s,mx}$	$T_{t,mx}$
2	$P_{sd,\max}$	$P_{td,\min}$	6	$P_{sox,\max}$	$P_{tox,\min}$	$T_{s,mx}$	$T_{t,mx}$
3	$P_{sd,\max}$	$P_{td,\max}$	7	$P_{sox,\max}$	$P_{tox,\max}$	$T_{s,mx}$	$T_{t,mx}$
4	$P_{sd,\min}$	$P_{td,\min}$	8	$P_{sox,\min}$	$P_{tox,\min}$	$T_{s,mx}$	$T_{t,mx}$

Table UIG-34-2
Values for Determining E^*/E and ν^* Equilateral Triangular Pattern

Coefficient [Note (1)]	Value	Coefficient [Note (1)]	Value
α_0	−0.0029	β_0	0.9966
α_1	0.2126	β_1	−4.1978
α_2	3.9906	β_2	9.0478
α_3	−6.173	β_3	−7.9955
α_4	3.4307	β_4	2.2398

NOTE:
(1) These coefficients are valid only for $0.1 \le \mu \le 0.6$.

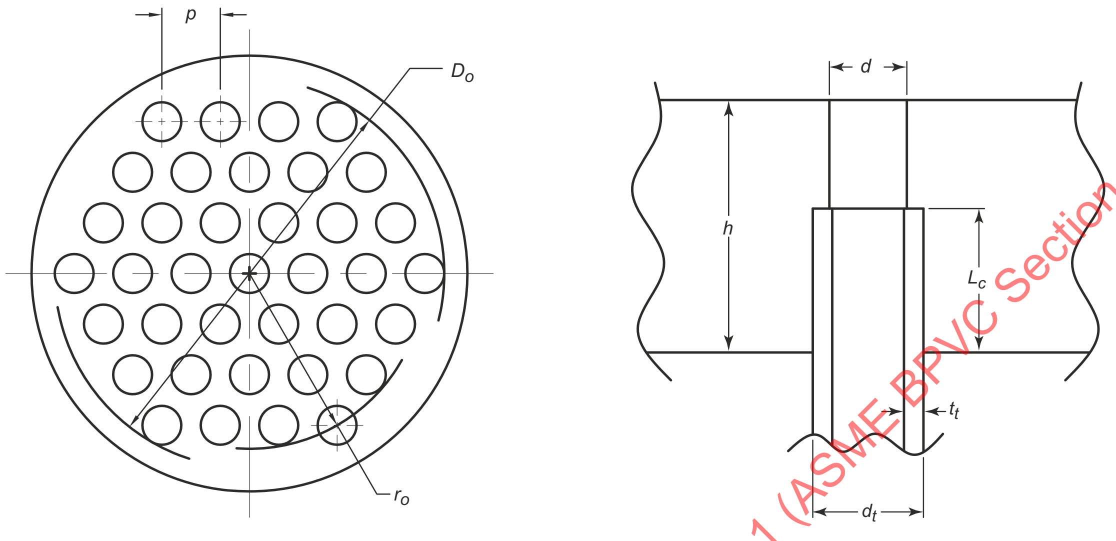
Table UIG-34-3
Values for Determining E^*/E and ν^* Equilateral Square Pattern

Coefficient [Note (1)]	Value	Coefficient [Note (1)]	Value
α_0	0.0372	β_0	0.3341
α_1	1.0314	β_1	0.1260
α_2	−0.6402	β_2	−0.6920
α_3	2.6201	β_3	0.6877
α_4	−2.1929	β_4	−0.0600

NOTE:
(1) These coefficients are valid only for $0.1 \le \mu \le 0.6$.

(25)

Figure UIG-34-4 Tubesheet Geometry



GENERAL NOTE: Any facing thicknesses or groove depths shall be in excess of the required minimum tubesheet thickness, h.

Table UIG-34-4 Formulas for Determination of Z_d, Z_v, Z_m, Z_w, and F_m

(1) Calculate Kelvin functions of order 0 relative to x, where x varies from 0 to X_a such that $0 < x \le X_a$ [Note (1)]:

$$\text{ber}(x) = \sum_{n=0}^{n=m-1} (-1)^n \frac{(x/2)^{4n}}{[(2n)!]^2} = 1 - \frac{(x/2)^4}{(2!)^2} + \frac{(x/2)^8}{(4!)^2} - \frac{(x/2)^{12}}{(6!)^2} + \ldots$$

$$\text{bei}(x) = \sum_{n=1}^{n=m} (-1)^{n-1} \frac{(x/2)^{4n-2}}{[(2n-1)!]^2} = \frac{(x/2)^2}{(1!)^2} - \frac{(x/2)^6}{(3!)^2} + \frac{(x/2)^{10}}{(5!)^2} - \ldots$$

and their derivatives:

$$\text{ber}'(x) = \sum_{n=1}^{n=m} (-1)^n \frac{(2n)(x/2)^{4n-1}}{[(2n)!]^2} = -\frac{2(x/2)^3}{(2!)^2} + \frac{4(x/2)^7}{(4!)^2} - \frac{6(x/2)^{11}}{(6!)^2} + \ldots$$

$$\text{bei}'(x) = \sum_{n=1}^{n=m} (-1)^{n-1} \frac{(2n-1)(x/2)^{4n-3}}{[(2n-1)!]^2} = \frac{(x/2)^1}{(1!)^2} - \frac{3(x/2)^5}{(3!)^2} + \frac{5(x/2)^9}{(5!)^2} - \ldots$$

(2) Calculate functions $\psi_1(x)$ and $\psi_2(x)$ relative to x:

$$\psi_1(x) = \text{bei}(x) + \frac{1-\nu^*}{x} \cdot \text{ber}'(x)$$

$$\psi_2(x) = \text{ber}(x) - \frac{1-\nu^*}{x} \cdot \text{bei}'(x)$$

Table UIG-34-4
Formulas for Determination of Z_d, Z_v, Z_m, Z_w, and F_m (Cont'd)

(3) Calculate Z_a, Z_d, Z_v, Z_w, and Z_m relative to X_a:

$$Z_a = \mathrm{bei}'(X_a) \cdot \psi_2(X_a) - \mathrm{ber}'(X_a) \cdot \psi_1(X_a)$$

$$Z_d = \frac{\mathrm{ber}(X_a) \cdot \psi_2(X_a) + \mathrm{bei}(X_a) \cdot \psi_1(X_a)}{X_a^3 \cdot Z_a}$$

$$Z_v = \frac{\mathrm{ber}'(X_a) \cdot \psi_2(X_a) + \mathrm{bei}'(X_a) \cdot \psi_1(X_a)}{X_a^2 \cdot Z_a}$$

$$Z_w = \frac{\mathrm{ber}'(X_a) \cdot \mathrm{ber}(X_a) + \mathrm{bei}'(X_a) \cdot \mathrm{bei}(X_a)}{X_a^2 \cdot Z_a}$$

$$Z_m = \frac{\mathrm{ber}'^2(X_a) + \mathrm{bei}'^2(X_a)}{X_a \cdot Z_a}$$

(4) Calculate functions $Q_m(x)$ and $Q_v(x)$ relative to x:

$$Q_m(x) = \frac{\mathrm{bei}'(X_a) \cdot \psi_2(x) - \mathrm{ber}'(X_a) \cdot \psi_1(x)}{Z_a}$$

$$Q_v(x) = \frac{\psi_1(X_a) \cdot \psi_2(x) - \psi_2(X_a) \cdot \psi_1(x)}{X_a \cdot Z_a}$$

(5) For each loading case, calculate $F_m(x)$ relative to x:

$$F_m(x) = \frac{Q_v(x) + Q_3 \cdot Q_m(x)}{2}$$

(6) F_m is the maximum of the absolute value of $F_m(x)$ when x varies from 0 to X_a such that $0 < x \le X_a$:

$$F_m = \max\left|F_m(x)\right|$$

NOTE:
(1) Use $m = 4 + X_a/2$ (rounded to the nearest integer) to obtain an adequate approximation of the Kelvin functions and their derivatives.

(25)

Table UIG-34-5
Formulas for Determination of $F_{t,\min}$ and $F_{t,\max}$

Step No.	Description
1	Follow steps (1), (2), and (3) in Table UIG-34-4.
2	Calculate functions $Z_d(x)$ and $Z_w(x)$ relative to x: $$Z_d(x) = \frac{\psi_2(X_a) \cdot \text{ber}(x) + \psi_1(X_a) \cdot \text{bei}(x)}{X_a^3 \cdot Z_a}$$ $$Z_w(x) = \frac{\text{ber}'(X_a) \cdot \text{ber}(x) + \text{bei}'(X_a) \cdot \text{bei}(x)}{X_a^2 \cdot Z_a}$$
3	For each loading case, calculate $F_t(x)$ relative to x in accordance with a or b below. *(a)* When $P_e \neq 0$ $$F_t(x) = \left[Z_d(x) + Q_3 \cdot Z_w(x)\right] \cdot \frac{X_a^4}{2}$$ *(b)* When $P_e = 0$ $$F_t(x) = Z_w(x) \cdot \frac{X_a^4}{2}$$
4	Calculate the minimum and maximum values, $F_{t,\min}$ and $F_{t,\max}$, of $F_t(x)$ when x varies from 0 to X_a such that $0 \leq x \leq X_a$. $F_{t,\min}$ and $F_{t,\max}$ may be positive or negative. $$F_{t,\min} = \min\left[F_t(x)\right]$$ $$F_{t,\max} = \max\left[F_t(x)\right]$$
	When $P_e \neq 0$, see ASME PTB-7 for a graphical representation of $F_{t,\min}$ and $F_{t,\max}$.

(25) UIG-35 CROSS-DRILLED BLOCKS

The minimum ligament thickness used on cross-drilled impervious graphite blocks shall conform to the following requirements:

(a) The minimum thickness of ligaments in a rectangular cross-drilled block shall be calculated by the following formulas [see Figure UIG-35-1, sketch (b) and Figure UIG-35-2]:

$$u_{r1} = 0.5d_1\left(\sqrt{1 + \frac{4P_1}{1.5S_t - P_1}} - 1\right) \quad (1)$$

$$u_{r2} = 0.5d_2\left(\sqrt{1 + \frac{4P_2}{1.5S_t - P_2}} - 1\right) \quad (2)$$

$$u_{rx} \geq \max\left[(u_1),(u_2)\right] \quad (3)$$

(b) The minimum thickness of ligaments in a cylindrical block shall be calculated using eq. (1) for axial chamber ligament, u_{r1}; eq. (3) for cross-ligament thickness, u_{rx}; and the following equation for radial chamber ligament, u_{r2}, [see Figure UIG-35-1, sketch (a) and Figure UIG-35-2]:

$$u_{r2} = 0.5d_2\left(\sqrt{1 + \frac{4P_2}{S_c - P_2}} - 1\right)$$

where

d_1 = hole diameter chamber 1 (axial chamber for cylindrical block)
d_2 = hole diameter chamber 2 (radial chamber for cylindrical block)
P_1 = design pressure chamber 1 (axial chamber for cylindrical block)
P_2 = design pressure chamber 2 (radial chamber for cylindrical block)
S_c = allowable compressive stress
S_t = allowable tensile stress
u_1 = ligament thickness chamber 1 (axial chamber for cylindrical block)
u_2 = ligament thickness chamber 2 (radial chamber for cylindrical block)
u_{r1} = minimum required ligament thickness chamber 1 (axial chamber for cylindrical block)
u_{r2} = minimum required ligament thickness chamber 2 (radial chamber for cylindrical block)
u_{rx} = minimum required cross-ligament thickness
u_x = cross-ligament thickness

UIG-36 OPENINGS AND REINFORCEMENTS (25)

(a) Openings in the graphite components of graphite pressure vessels and pressure vessel parts do not require reinforcement other than that inherent in the construction when the openings are fully supported by metallic covers or backing plates that have been designed and fabricated in accordance with this Division. An opening is considered fully supported when it has a metallic cover or backing plate in full continuous contact with the graphite component as follows:

(1) For cylindrical components, the method shall be either a cemented assembly, a press-fit assembly, or a shrink-fit assembly that provides continuous contact between a metallic cylinder and the graphite component.

(2) For flat heads and covers, the method shall be either a cemented assembly or a full-contact gasket or similar backing pad.

(b) The metallic cover or backing plate shall cover the full limit of reinforcement as defined in (1) and (2).

(1) For cylindrical components, the length of the supporting cover shall extend a distance on each side of the axis of the opening equal to the diameter of the finished opening.

(2) For flat heads and covers, the backing plate shall have flat and continuous contact across the entire contact area of the graphite component.

(c) When the condition in (a) is not met, openings shall be reinforced per the requirements of Part UG insofar as they are applicable to graphite pressure equipment.

(d) Unacceptable nozzle configurations include those shown in Figure UIG-36-1. The acceptable nozzle configurations include but are not limited to those shown in Figure UIG-36-2.

Figure UIG-35-1
Cross-Drilled Blocks (25)

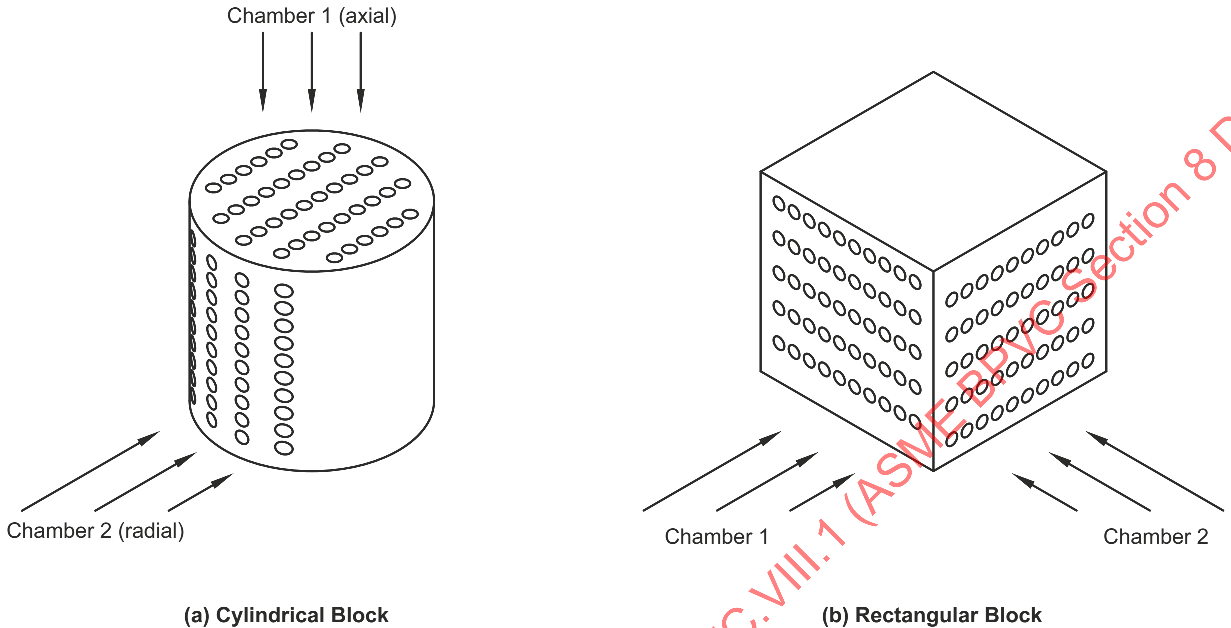


Figure UIG-35-2
Cross-Drilled Block Ligaments (25)

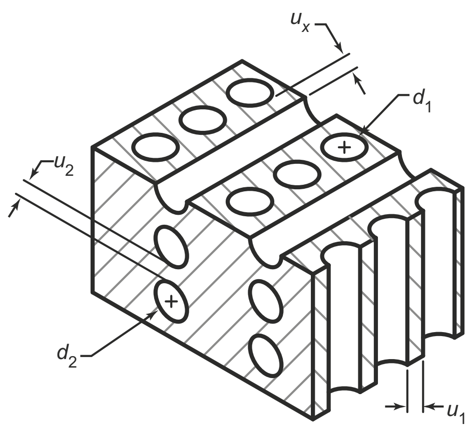
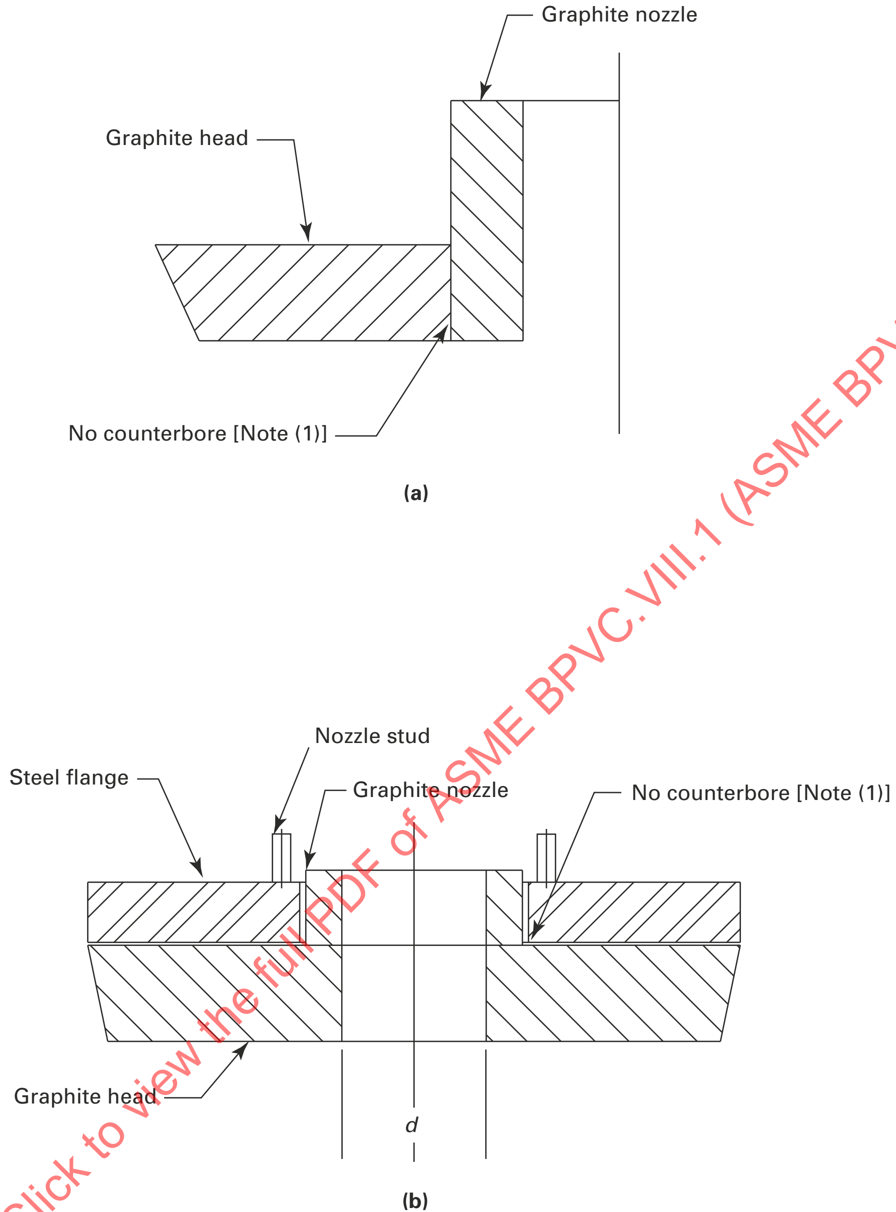


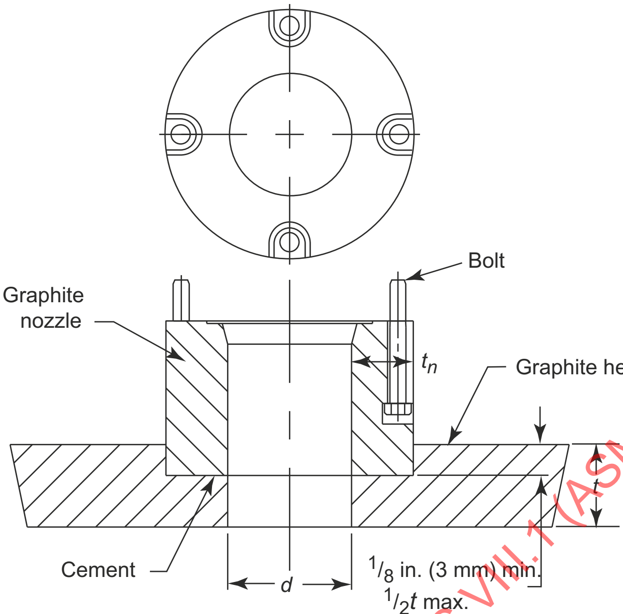
Figure UIG-36-1
Unacceptable Nozzle Attachment Details



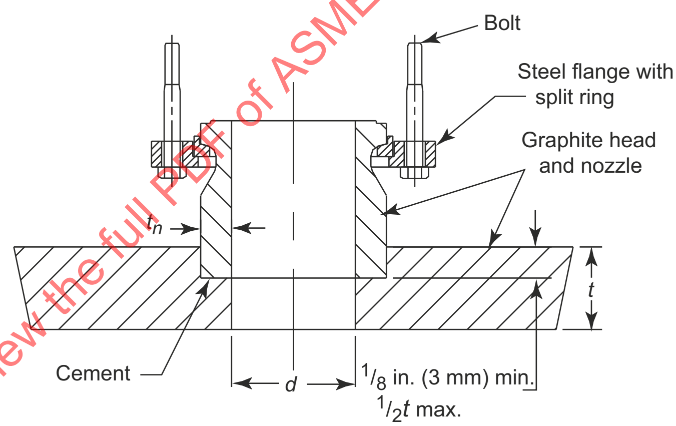
NOTE:
(1) See Figure UIG-36-2, sketch (b) for acceptable version.

(25)

Figure UIG-36-2
Some Acceptable Nozzle Attachment Details in Impervious Graphite Pressure Vessels

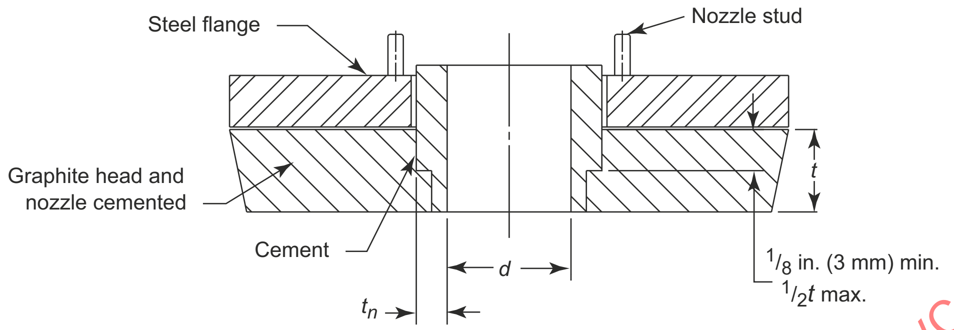


(a) Insert Joint

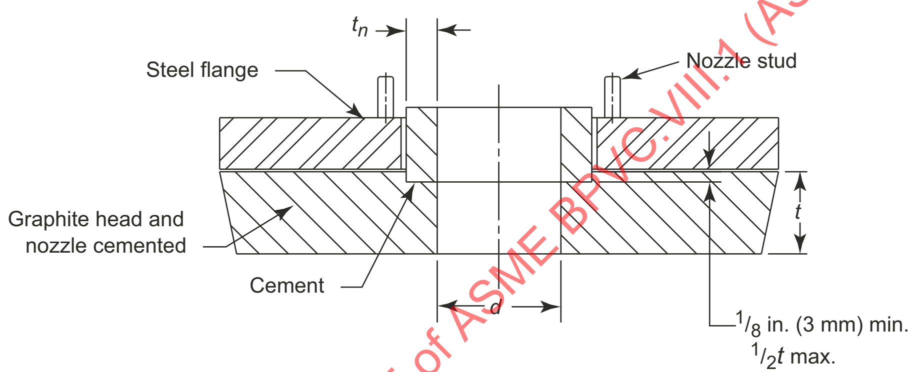


(b) Split Ring

Figure UIG-36-2
Some Acceptable Nozzle Attachment Details in Impervious Graphite Pressure Vessels (Cont'd)

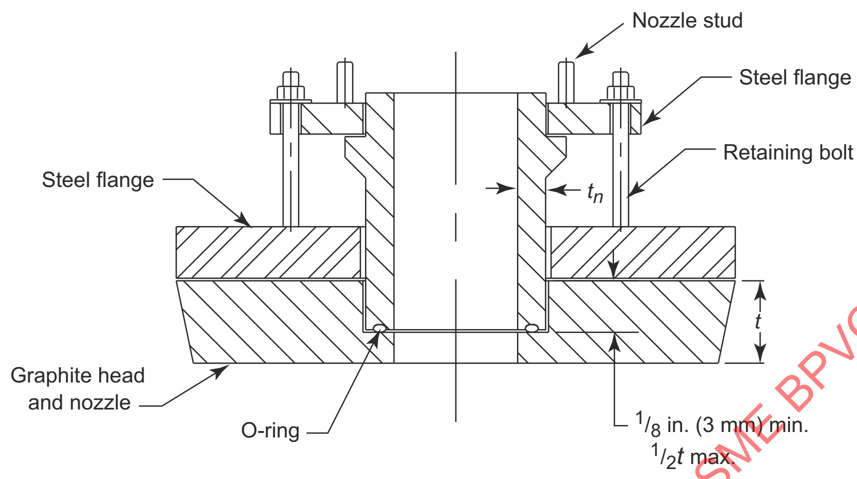


(c) Deep Counterbore

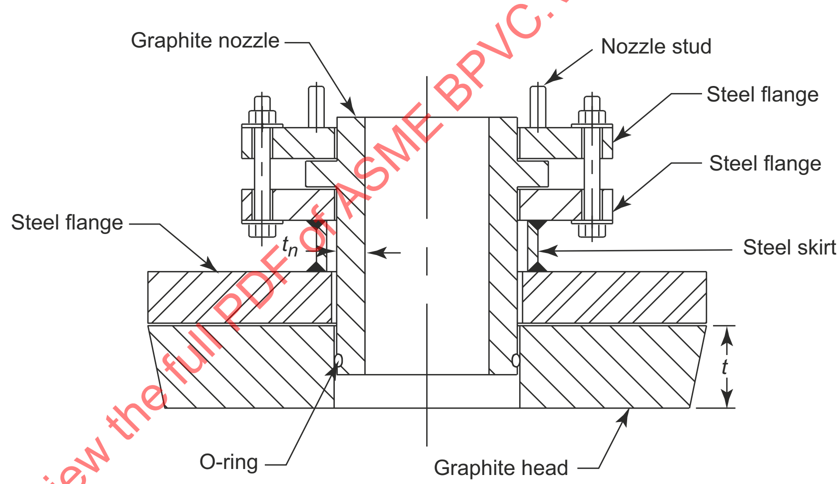


(d) Shallow Counterbore

Figure UIG-36-2
Some Acceptable Nozzle Attachment Details in Impervious Graphite Pressure Vessels (Cont'd)

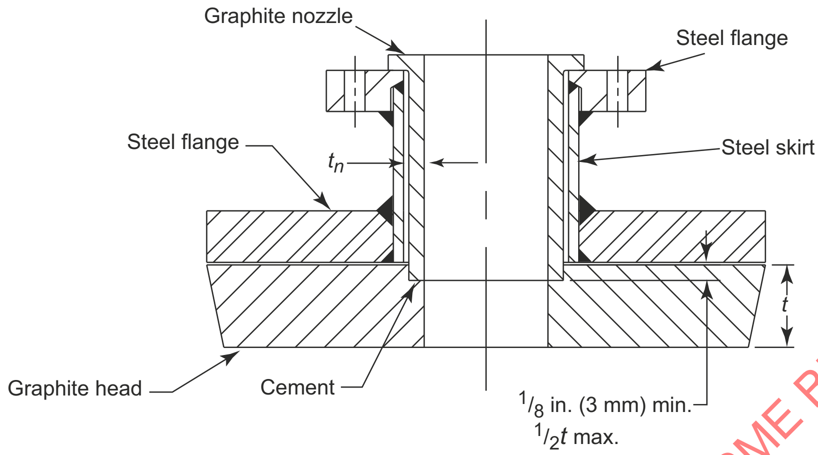


(e) O-Ring

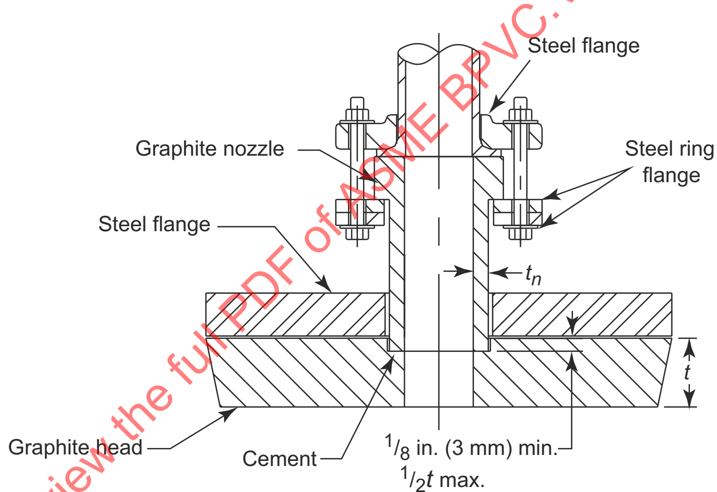


(f) O-Ring

Figure UIG-36-2
Some Acceptable Nozzle Attachment Details in Impervious Graphite Pressure Vessels (Cont'd)



(g) Shrouded Flanged



(h) Split Ring Flanged

(25) UIG-45 NOZZLE NECK THICKNESS

The minimum nozzle neck thickness, t_n, shall be $^1/_2$ in. (13 mm) for nozzles of 3 in. (75 mm) nominal inside diameter or larger, and $^1/_4$ in. (6 mm) for nozzles less than 3 in. (75 mm) nominal inside diameter, but in no case less than the thickness required by UIG-27 or UIG-28 as appropriate.

UIG-60 LETHAL SERVICE

Graphite pressure vessels and vessel parts to be used for lethal service, as defined in UW-2(a), shall meet the following additional requirements:

(a) The design factor shall be 7.0 for lethal service.

(b) In addition to the testing requirements in Table UIG-84-1, all graphite components for lethal service, excluding tubes, shall be tested per UIG-84 requirements at room temperature to determine mechanical properties.

(c) All interior corners of pressure components shall have a $^1/_2$ in. (13 mm) minimum radius.

(d) Exposed graphite shall be shielded with a metal shroud. This shroud shall be constructed per the rules of this Division, but is exempt from NDE and pressure testing requirements.

It is strongly recommended that owners/users monitor the permeability of graphite equipment in lethal service.

FABRICATION

(25) UIG-75 GENERAL REQUIREMENTS

The fabrication of graphite pressure vessels and vessel parts shall conform to the general requirements of this Division and to the specific requirements for Fabrication given in Part UIG.

(a) Each Manufacturer shall be responsible for the quality of the materials, processes, and personnel used by their organization, and shall conduct tests of the processes to ensure that materials and completed joints comply with the requirements of this Part.

(b) The design of pressure-containing and structural-cemented joints shall be limited to those qualified in accordance with the Manufacturer's Cementing Procedure Qualification (CPQ) (see UIG-79).

(c) No production cementing shall be undertaken until after the cementing procedures and the cementing technicians to be used in production have been qualified.

(d) Each cementing technician shall be assigned an identifying number, letter, or symbol by the Manufacturer, which shall be used to identify the technician's work.

(e) The Manufacturer shall maintain a continuity record for each cementing technician showing the date, the results of tests, and the identification mark assigned to each. These records shall be certified by the Manufacturer and shall be accessible to the Authorized Inspector.

(f) The cementing technician shall mark the work, or the Manufacturer may record the cementing technician's I.D. number on a drawing or similar document traceable to the joint or seam. When multiple operators are cementing tubes to tubesheets, the Manufacturer shall record all cementing technicians' identification numbers on a drawing or similar document.

(g) The bulk temperature of the material to be joined shall be between 50°F (10°C) and 125°F (52°C) during the cementing operation.

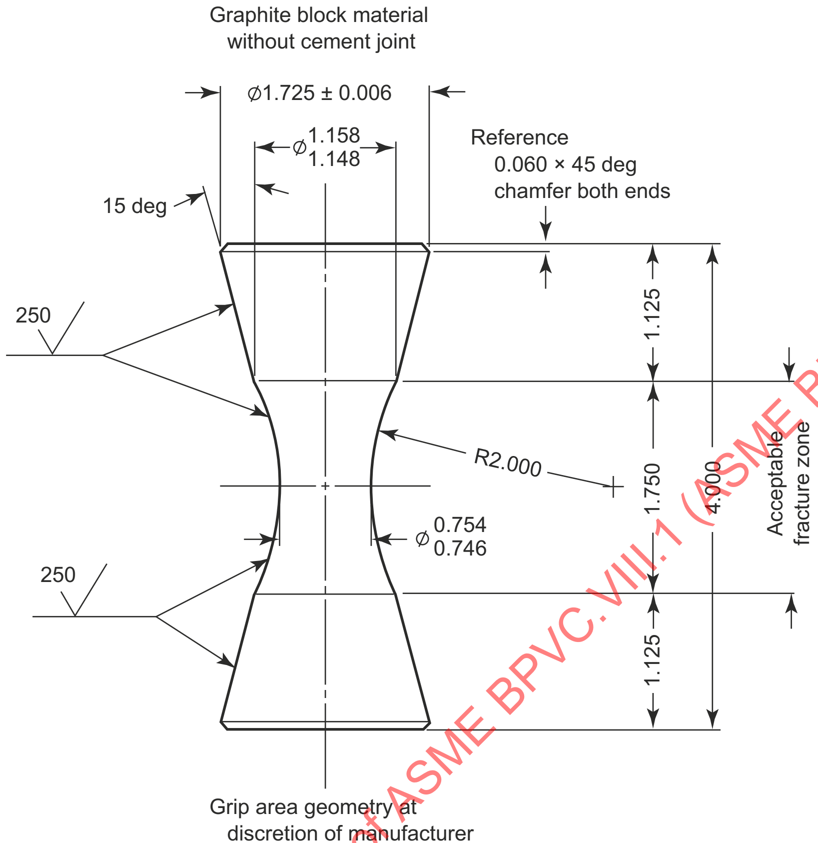
UIG-76 PROCEDURE AND PERSONNEL QUALIFICATION (25)

(a) Material manufacturing shall not be undertaken until after the material specifications have been qualified. Production cementing activities shall not be undertaken until after the cementing procedures and cementing technicians have been qualified (see UIG-79 and UIG-80).

(b) Tensile test specimens shall comply with Figure UIG-76-1 (Figure UIG-76-1M), Figure UIG-76-2 (Figure UIG-76-2M), Figure UIG-76-3 (Figure UIG-76-3M), Figure UIG-76-4 (Figure UIG-76-4M), Figure UIG-76-5 (Figure UIG-76-5M), or Figure UIG-76-6 (Figure UIG-76-6M).

(25)

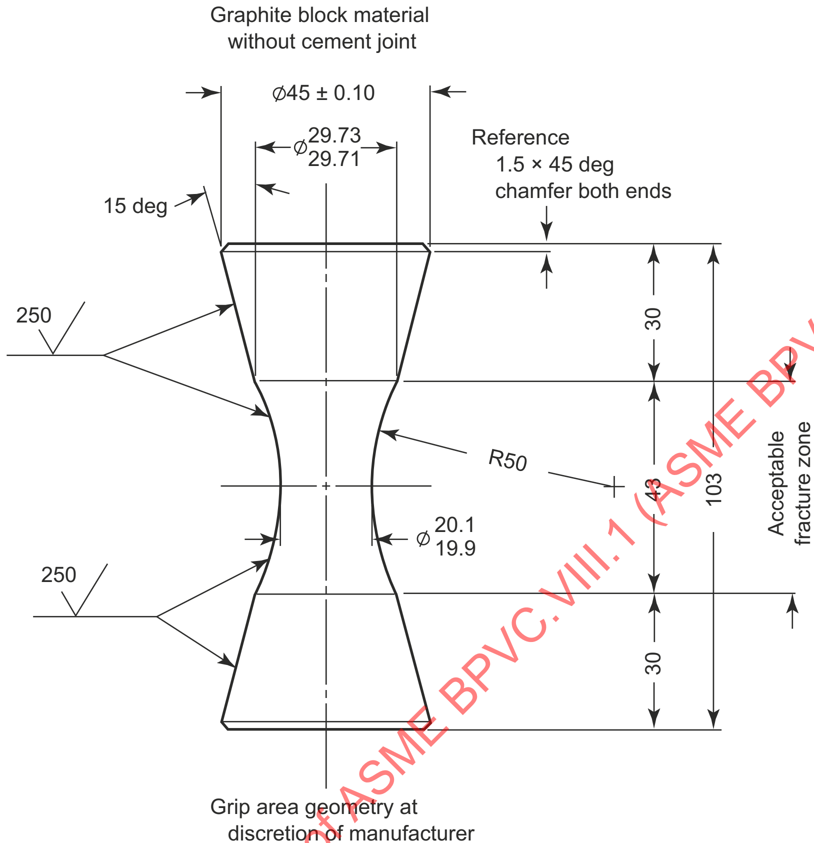
Figure UIG-76-1
Block Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in inches.
(b) Except as noted, tolerance = ±0.010.

(25)

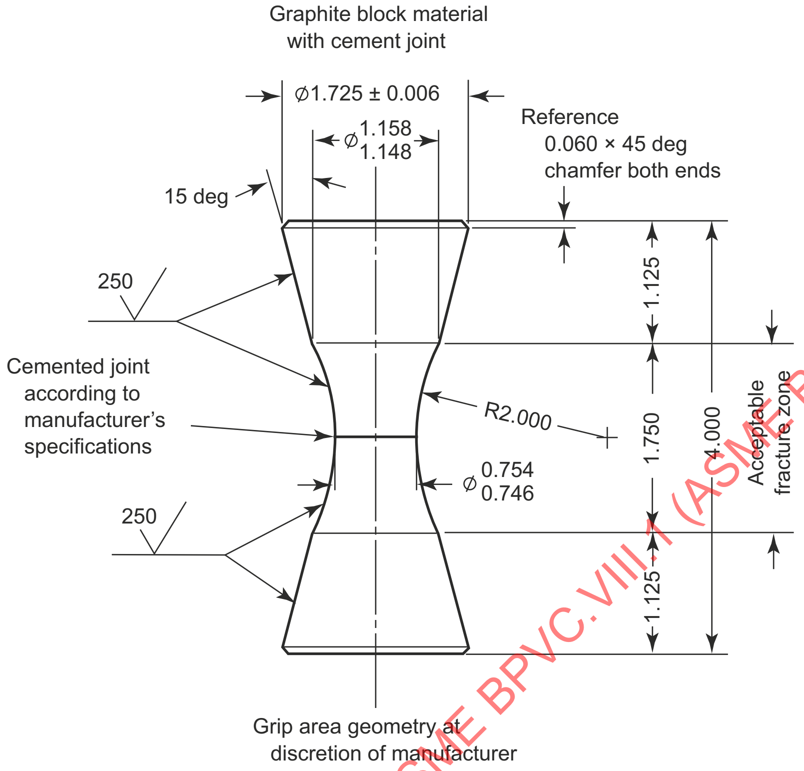
Figure UIG-76-1M
Block Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in millimeters.
(b) Except as noted, tolerance = ±0.25.

(25)

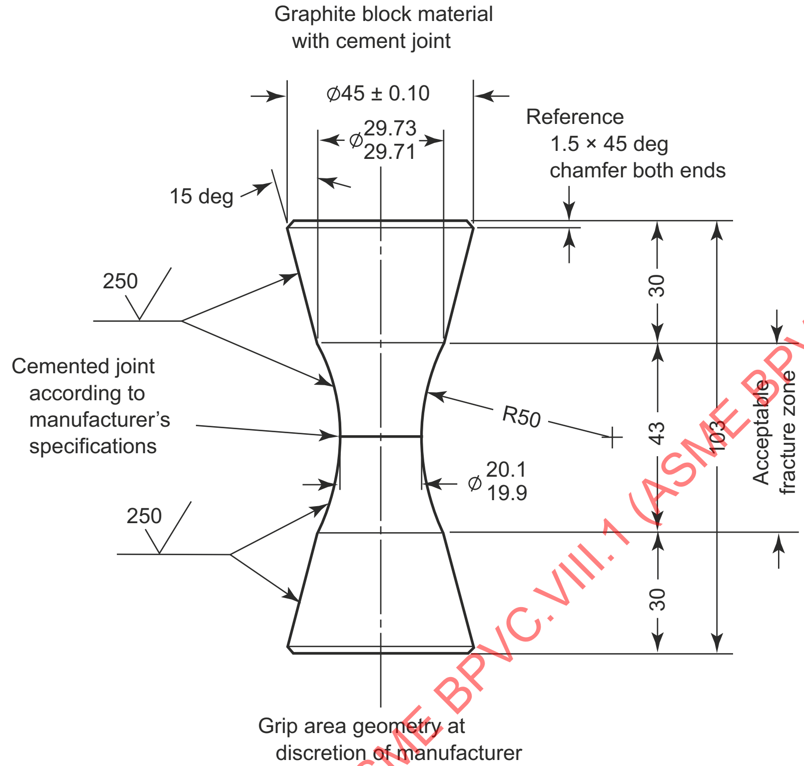
Figure UIG-76-2
Cement Material Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in inches.
(b) Except as noted, tolerance = ±0.010.

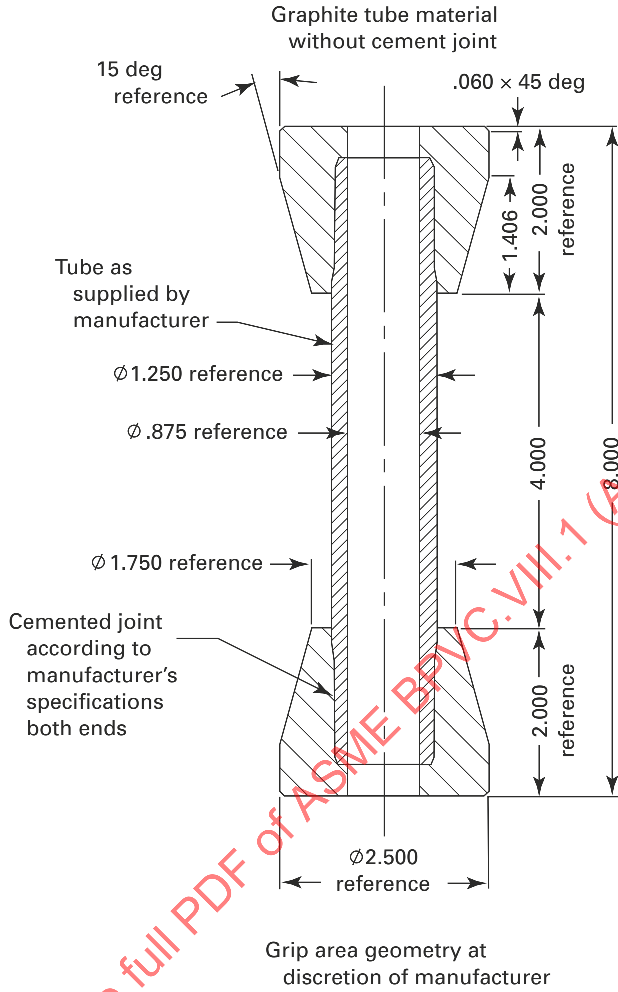
Figure UIG-76-2M
Cement Material Tension Test Specimen

(25)



GENERAL NOTES:
(a) All dimensions are in millimeters.
(b) Except as noted, tolerance = ±0.25.

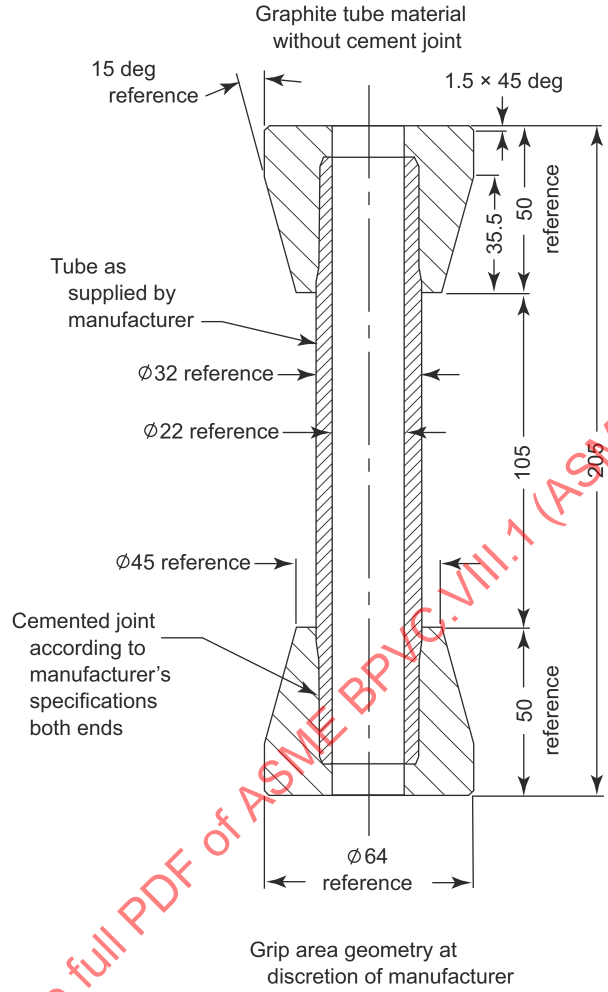
Figure UIG-76-3
Tube-to-Tubesheet Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in inches.
(b) Except as noted, tolerance = ±0.010.

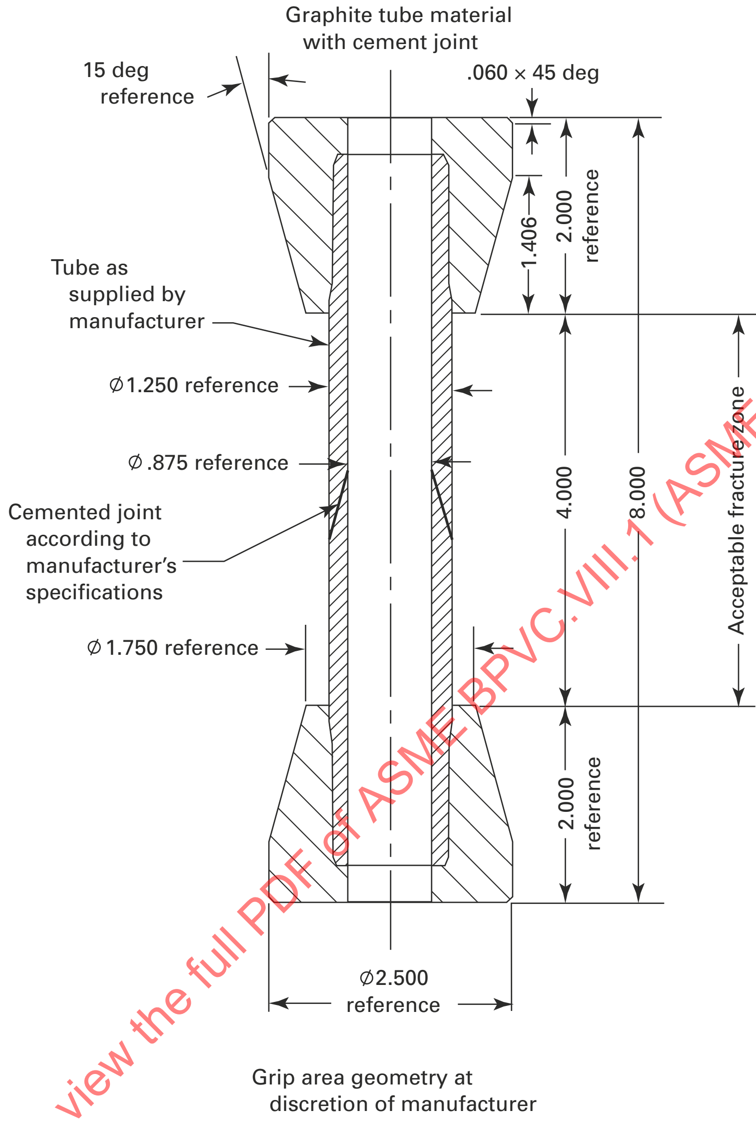
(25)

Figure UIG-76-3M
Tube-to-Tubesheet Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in millimeters.
(b) Except as noted, tolerance = ±0.25.

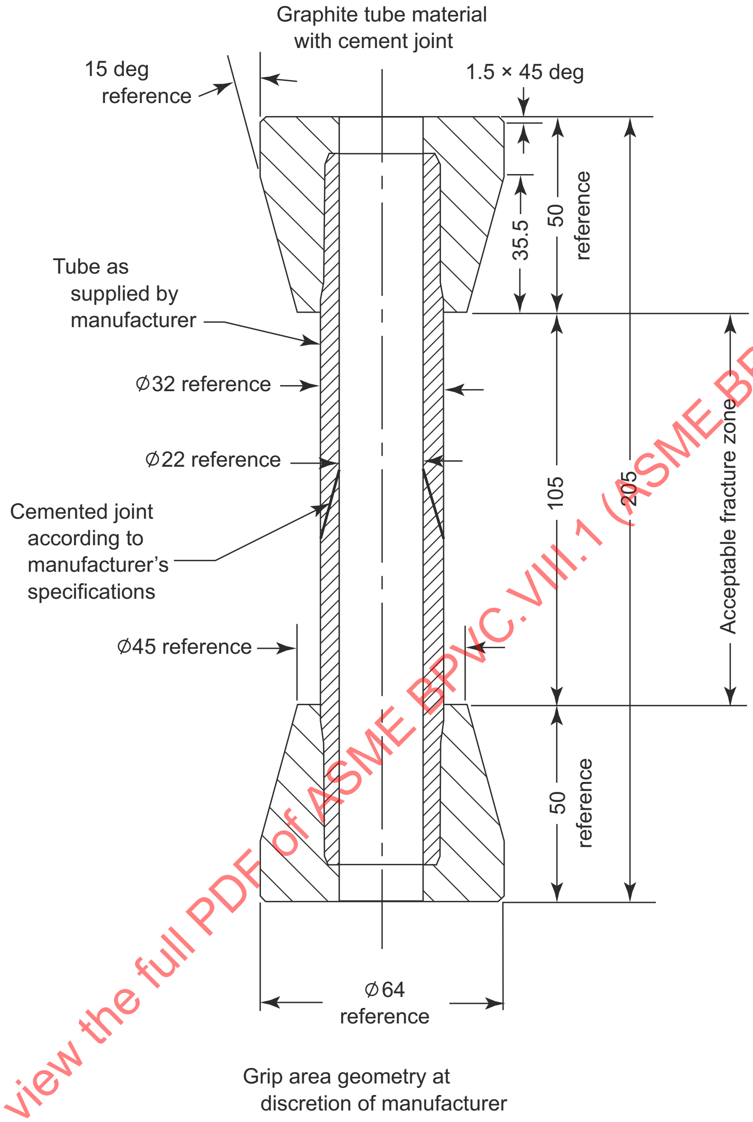
Figure UIG-76-4
Tube Cement Joint Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in inches.
(b) Except as noted, tolerance = ±0.010.

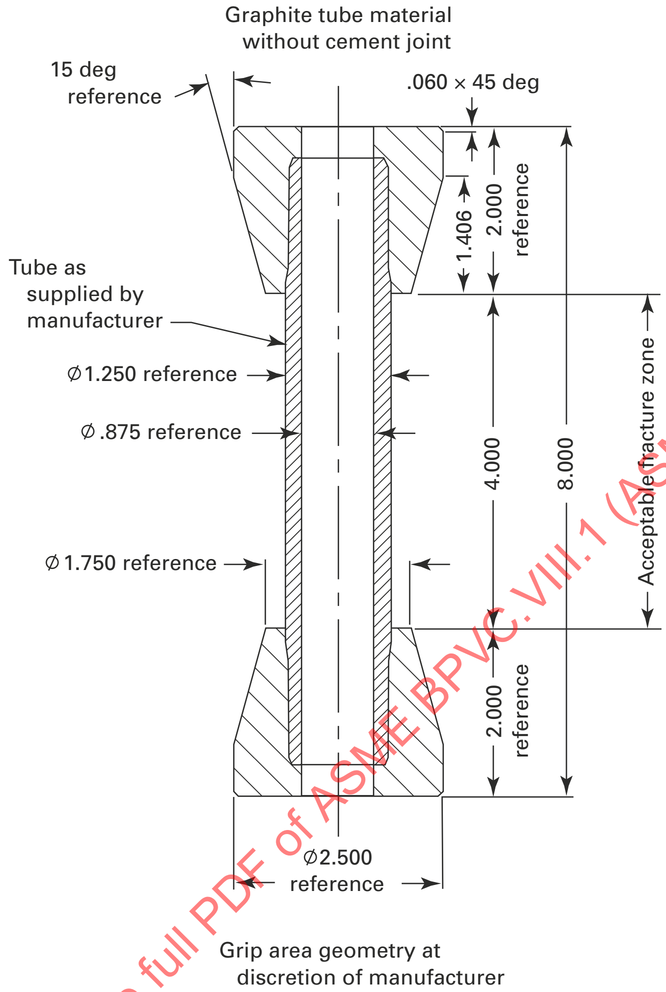
(25)

Figure UIG-76-4M
Tube Cement Joint Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in millimeters.
(b) Except as noted, tolerance = ±0.25.

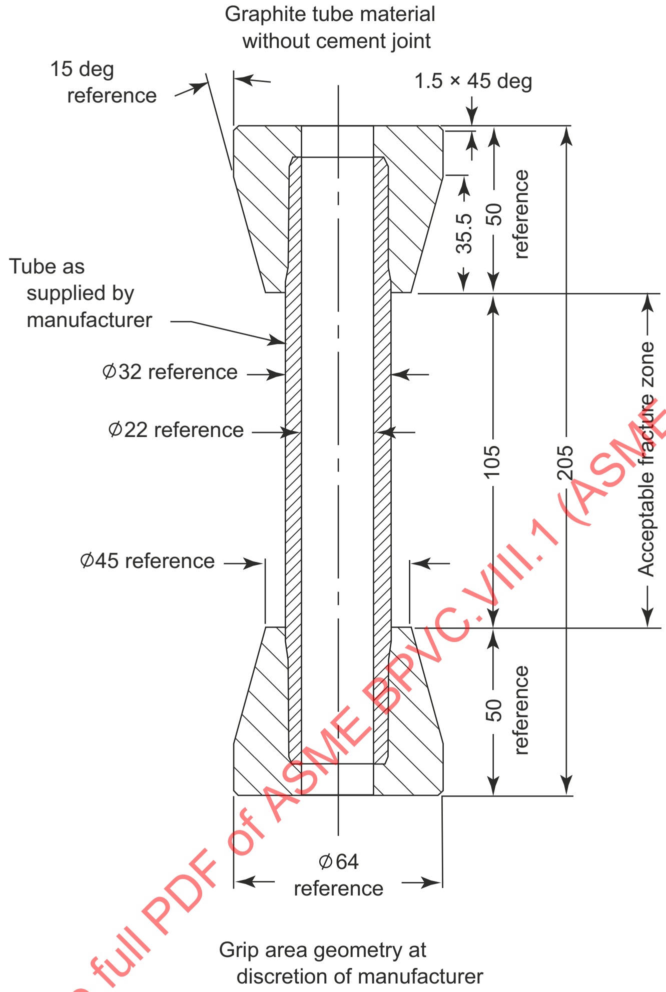
Figure UIG-76-5
Tube Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in inches.
(b) Except as noted, tolerance = ±0.010.

(25)

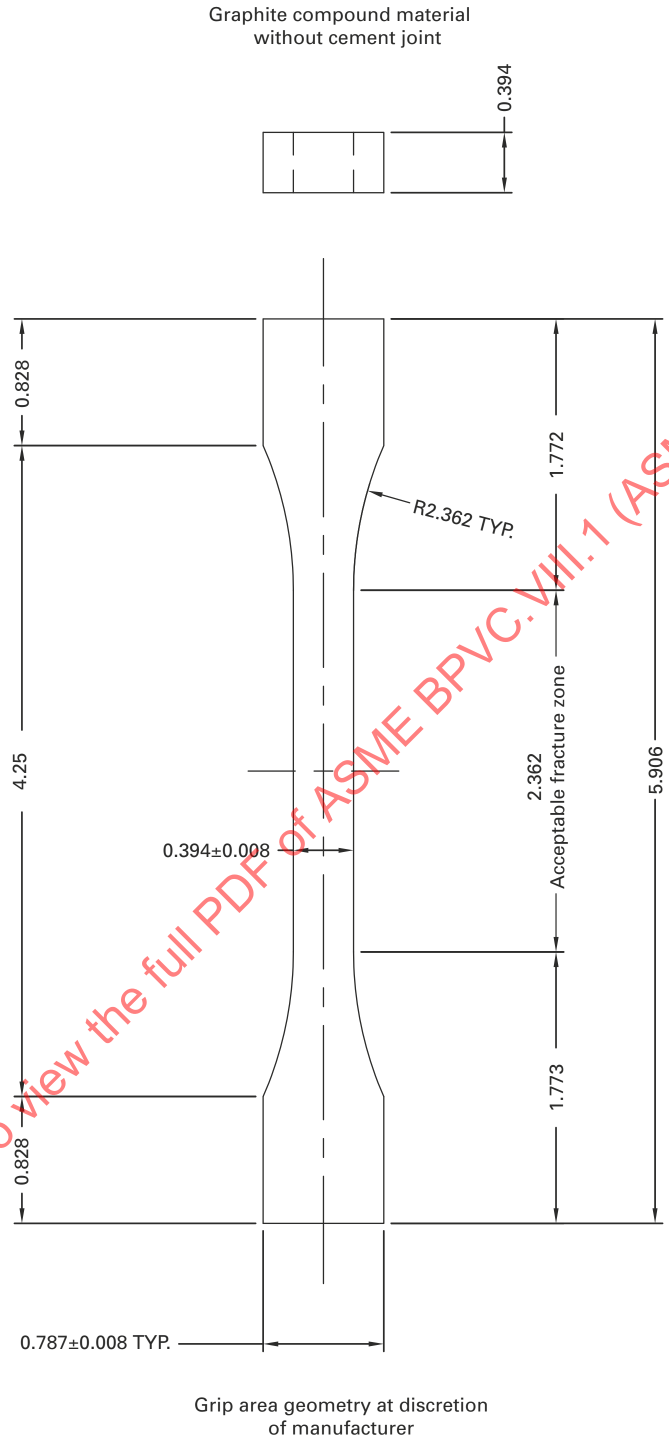
Figure UIG-76-5M
Tube Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in millimeters.
(b) Except as noted, tolerance = ±0.25.

(25)

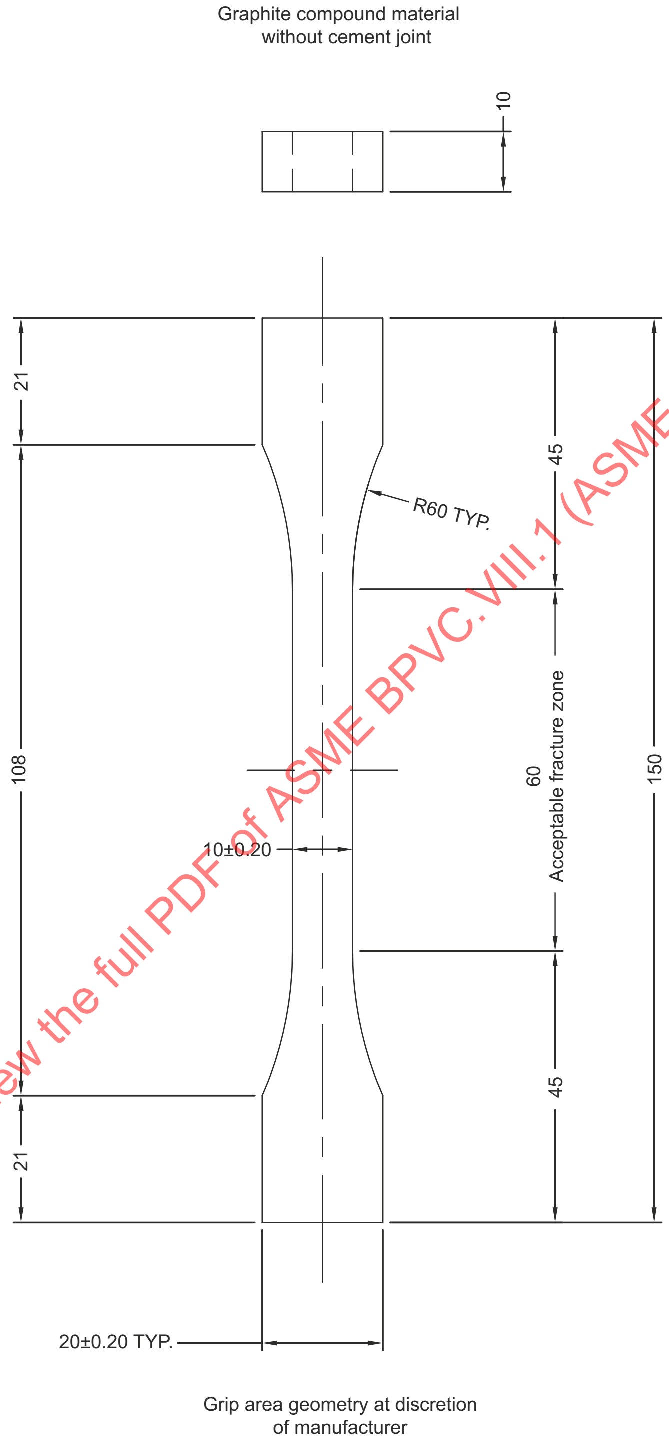
Figure UIG-76-6
Compound Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in inches.
(b) Except as noted, tolerance = ±0.010.

(25)

Figure UIG-76-6M
Compound Tension Test Specimen



GENERAL NOTES:
(a) All dimensions are in millimeters.
(b) Except as noted, tolerance = ±0.25.

(c) Tensile tests shall be performed as described in UIG-102.

(d) Compressive strength tests shall be performed as described in UIG-103.

(e) Flexural strength tests shall be performed as described in UIG-101.

(25) UIG-77 CERTIFIED MATERIAL SPECIFICATION

(a) The Manufacturer shall prepare a Certified Material Specification (CMS) to ensure that the material meets the requirements of Table UIG-6-1. The CMS shall include the raw materials and processes necessary to manufacture certified material. The CMS shall include all essential and non-essential variables with tolerance ranges.

(b) The Manufacturer shall qualify the Certified Material Specification (CMS) using the Certified Material Qualification Form CMQ. Ten specimens are required for each test.

(c) Any change to any essential variable, including the tolerance range, requires requalification of the CMS.

(d) The essential variables to be included in the qualification of a CMS are as follows:

(1) Carbon or graphite material:

(-a) manufacturer

(-b) grade or number

(-c) density range

(-d) grain size range

(2) Impregnation agent or binder system materials:

(-a) manufacturer

(-b) type/resin system

(-c) specific gravity range

(-d) viscosity range at room temperature

(-e) significant ingredients with range

(3) Impregnation or curing process:

(-a) process pressure ranges

(-b) process time ranges

(-1) under vacuum

(-2) under pressure

(-3) at temperature

(-c) process temperature ranges

(-d) vacuum ranges

(e) Nonessential variables are those elements that the Manufacturer may include in the CMS to provide direction in producing certified material, but that do not affect the resulting properties of the material. Changes to nonessential variables do not require requalification of the CMS.

(f) Tests to be included for Certified Material Qualification (CMQ) shall include the following:

(1) Impregnated Material

(-a) flexural strength (tubes only)

(-b) tensile strength at both room and maximum allowable material temperature

(-c) compressive strength at both room and maximum allowable material temperature

(-d) coefficient of thermal expansion

(-e) coefficient of permeability

(2) Compound Material

(-a) tensile strength at both room and maximum allowable material temperature

(-b) compressive strength at both room and maximum allowable material temperature

(-c) coefficient of thermal expansion

(-d) coefficient of permeability

(-e) modulus of elasticity at both room and maximum allowable material temperature

UIG-78 CERTIFIED CEMENT SPECIFICATION (25)

(a) The Manufacturer shall prepare a Certified Cement Specification (CCS). The CCS shall include the raw materials and processes necessary to manufacture certified cement. The CCS shall include all essential and non-essential variables with tolerance ranges, including shelf life and storage recommendations.

(b) The manufacturer shall qualify the CCS using a Certified Cement Qualification (CCQ) form, Form CCQ. The CCQ shall include all essential variables and the actual test results.

(c) Any change to any essential variable, including the tolerance range, shall require requalification of the CCS.

(d) The essential variables to be included in the qualification of a CCS are as follows:

(1) Cement material data

(-a) filler material

(-b) resin material

(-c) accelerator material

(2) Curing process (i.e., time, temperature)

(e) Nonessential variables are those elements that the Manufacturer may include in the CCS to provide direction in producing certified cement, but that do not affect the resulting properties of the material. Changes to nonessential variables do not require requalification of the CCS.

The CCS qualification shall include tensile strength testing at both room and maximum allowable material temperatures. (See UIG-102.)

UIG-79 CERTIFIED CEMENTING PROCEDURE SPECIFICATION (25)

(a) The Manufacturer shall prepare a Cementing Procedure Specification (CPS). The CPS shall include the materials and processes necessary to manufacture items using certified material and certified cement. The CPS shall include all essential and non-essential variables with tolerance ranges.

(b) The Manufacturer shall qualify the Cementing Procedure Specification using a Cementing Procedure Qualification (CPQ) form, Form CPQ. The CPQ shall include all essential variables and the actual test results.

(c) Any change to any essential variable, including the tolerance range, shall require requalification of the CPS.

(d) The essential variables to be included in the qualification of a CPS are as follows:

(1) joint design with clearances

(2) certified cement specification

(3) surface preparation

(4) curing time and temperature range

(e) Tests to be included for Certified CPQ shall include tensile strength (see UIG-102).

UIG-80 CEMENTING TECHNICIAN QUALIFICATION

(a) A cementing technician is any individual who is responsible for proper joint preparation, cleaning of parts to be joined, mixing cement, applying cement, securing the joint during curing, and monitoring the curing process.

(b) The Manufacturer shall qualify technicians to be used in fabrication of graphite vessels and parts. The Manufacturer shall document qualification of the technician using a Cementing Technician Qualification Form CTQ.

(c) Tests to be included for Cement Technician Qualification shall include four tensile strength tests using specimens shown in Figure UIG-76-2.

(d) Technicians shall be requalified when they have not been actively engaged in production of graphite pressure vessels within 6 months or when there is a reason to question their ability to complete a sound joint.

(25) UIG-81 REPAIR AND ACCEPTANCE STANDARDS OF CERTIFIED MATERIALS

(a) Certified materials may be repaired using the Manufacturer's qualified procedures and specifications, provided the concurrence of the Authorized Inspector is first obtained for the method and extent of repairs. Defective certified materials that cannot be satisfactorily repaired shall be rejected. Raw graphite materials shall not be repaired by application of cement or by joining other material by cementing.

(b) The Manufacturer shall

(1) create a documented repair plan, reviewed and accepted by the Authorized Inspector, for completing the repair

(2) document the repair using the Manufacturer's nonconformance procedure identified in the Manufacturer's quality control system

(3) document examination of the repair on a report of examination in accordance with Section V, Article 9, T-990.

(c) Only certified materials, including certified cement, shall be used for repairs. The certified materials used shall possess strength properties that exceed or equal the properties of the material to be repaired.

(d) Repairs to certified materials other than tubes include but are not limited to the following:

(1) Defects that are $^1/_8$ in. to $^3/_{16}$ in. (3 mm to 4.7 mm) in depth may be repaired by filling in the defect with cement using the Manufacturer's qualified procedures and specifications.

(2) Defects with a depth greater than $^3/_{16}$ in. (4.7 mm) shall be removed in their entirety and repaired using the Manufacturer's qualified procedures and specifications.

(e) Cracks in tubes shall not be repaired. Defective tube sections may be removed so that the remainder of the tube can be used. Individual tube sections shall not be less than 24 in. (610 mm) in length. The finished tube shall not include more than two repair splices.

(f) The repair shall neither result in sharp edges nor in the finished thickness being less than the minimum design thickness. The surface shall be free of any visible laminations, spalling, or cracks. In addition

(1) for tubes, scratches, gouges, grooves, etc., are permitted up to $^1/_{32}$ in. (0.8 mm) in depth

(2) for all other certified material, scratches, gouges, voids, grooves, etc., are permitted up to $^1/_8$ in. (3 mm) in depth

UIG-84 REQUIRED TESTS (25)

(a) General. The required tests of certified material shall be conducted at the frequency specified in Table UIG-84-1.

(b) Impregnated and Compound Material

(1) The tensile strength test defined in UIG-102 and the compressive strength test defined in UIG-103 shall be used to establish the strength of the material.

(2) The test specimens shall be taken in accordance with UIG-102 and UIG-103.

(3) For each lot of material, the tested strength values shall be within 20% of the average value determined during the certified material qualification tests.

(4) For each lot of impregnated tube material, the flexural strength (see UIG-101) shall be multiplied by the factors determined during material qualification to calculate the tensile and compressive strength values for the lot.

(5) When the average value of the five specimens tested in accordance with UIG-84 exceeds the minimum value required for the lot, but the value for one specimen is below the minimum value permitted for a single specimen (see Table UIG-6-1), a retest of five additional specimens shall be made. If the second set fails, the batch shall be rejected.

(6) The tensile and compressive strength values obtained in accordance with UIG-84 shall be equal to or greater than the values listed in Table UIG-6-1.

(7) After impregnation or final production, and prior to cementing or installing, all heat exchanger tubes shall be subjected to an internal pressure test at a minimum of 290 psi (2.0 MPa) or 2 times the tube internal design pressure, P_t, whichever is greater. The Authorized Inspector is not required to witness this test. The results of this test shall be documented by the tube Manufacturer.

(c) Cement Material

(1) The tensile strength test defined in UIG-102 shall be used to establish the strength of certified cement material.

(25)

Table UIG-84-1
Test Frequency for Certified Materials

Property	Testing Frequency
Flexural strength	Impregnated Tubes: Tested property at time of certified material qualification, for each lot [Note (1)], and at minimum, every 3 months.
Compressive strength	(a) Impregnated Tubes: Only at time of certified material qualification, thereafter calculated property based on specific relationship with flexural strength tests. (b) Compound Tubes: Tested property at time of certified material qualification, for each lot, and at minimum, every 3 months. (c) Impregnated Blocks: Tested property at time of certified material qualification, for each lot, and at minimum, every 3 months (shall be across the grain). (d) Compound Blocks: Tested property at time of certified material qualification, for each lot, and at minimum, every 3 months.
Tensile strength	(a) Impregnated Tubes: Only at time of certified material qualification, thereafter calculated property based on specific relationship with flexural strength tests. (b) Compound Tubes: Tested property at time of certified material qualification, for each lot, and at minimum, every 3 months. (c) Impregnated Blocks: Tested property at time of certified material qualification, for each lot, and at minimum, every 3 months (shall be across the grain). (d) Compound Blocks: Tested property at time of certified material qualification, for each lot, and at minimum, every 3 months.
Tensile strength at maximum material temperature	At time of certified material qualification for impregnated tubes, impregnated blocks, compound tubes, compound blocks, and cement (impregnated blocks shall be across the grain). (This test may be used in lieu of the room temperature lot test.)
Compressive strength at maximum material temperature	At time of certified material qualification for all material types. (Impregnated block material tests shall be across the grain). (This test may be used in lieu of the room temperature lot test.)
Cement tensile strength	The cement manufacturing process shall be certified. Based on this certification, the test shall be performed at the time of certified material qualification and verified by testing five samples every 3 months.
Coefficient of thermal expansion	The value shall be determined by tests performed at the time of certified material qualification. The value shall be made available by the Manufacturer.
Coefficient of permeability	The value shall be determined by tests performed at the time of certified material qualification. The value shall be made available by the Manufacturer.
Modulus of elasticity	Compound Tubes: The value shall be determined based on 10 test specimens at the time of certified material qualification, and be appended to Form CMQ.
Modulus of elasticity at maximum material temperature	Compound Tubes: The value shall be determined based on 10 test specimens at the time of certified material qualification, and be appended to Form CMQ.

NOTE:
(1) A "lot" is that quantity of specific grade of certified material produced within a 3-month period that meets established specifications for material properties.

(2) The test specimens shall comply with Figure UIG-76-2 for tension testing.

(3) For each lot of material, the strength values shall be within 20% of the average value determined during the certified material qualification tests.

(4) When the average value of the five specimens tested in accordance with UIG-84 exceeds the minimum value permitted for a single specimen, and when the value for one specimen is below the minimum value permitted for a single specimen, a retest of five additional specimens shall be made. If the second set fails, the batch is rejected.

(5) The tensile strength values obtained in accordance with UIG-84 shall be equal to or greater than the values listed in Table UIG-6-1.

INSPECTION AND TESTS

UIG-90 GENERAL

The general requirements of UG-90 of this Division apply insofar as these requirements are applicable to graphite pressure vessels.

UIG-95 VISUAL EXAMINATION

(a) Parts, material, finished joints, and completed vessels shall be visually examined by the Manufacturer over the full surface to detect defects. Surfaces that are accessible for visual examination after the vessel is completed need not be examined before completion of the vessel or vessel parts; however, such examination shall occur prior to the final pressure test.

(b) The Manufacturer shall prepare and qualify a written procedure that meets the requirements of Section V, Article 9 (Visual Examination). The procedure qualification shall be subject to and demonstrated to the Authorized Inspector.

(c) The Manufacturer shall designate qualified personnel for Visual Examination.

(d) All cemented nozzles must be examined to ensure that cement has flowed around the entire perimeter and that full penetration through the depth of the joint has been achieved.

UIG-96 QUALIFICATION OF VISUAL EXAMINATION PERSONNEL

Personnel who perform the Visual Examinations shall be qualified and certified for this method in accordance with a program established by the employer of the personnel being certified, which shall be based on the following minimum requirements:

(a) instruction in the fundamentals of the visual examination method.

(b) on-the-job training to familiarize the personnel with the appearance and interpretation of indications of defects. The length of time for such training shall be sufficient to ensure adequate assimilation of the knowledge required.

(c) An eye examination shall be performed per the requirements of Section V, Article 9 to determine near-distance acuity of personnel to perform the required examination.

(d) Upon completion of (a) and (b) above, the personnel shall be given an oral or written examination and performance examination to determine if the personnel are qualified to perform the required examination and interpret the results.

(e) Certified personnel whose work has not included performance of visual examination for a period of 1 yr or more shall be re-certified by completing (a) through (d) above.

UIG-97 ACCEPTANCE STANDARDS AND DOCUMENTATION (25)

See UIG-81.

UIG-99 PRESSURE TESTS

Completed pressure vessels shall be subjected to a hydrostatic test in accordance with the requirements of UG-99. The lowest ratio for impervious graphite material for the stress value at the test temperature to the stress value at the design temperature shall be taken as 1.0. The inspection for leaks of all joints and connections shall be made at a pressure not less than the MAWP.

UIG-101 STANDARD TEST METHOD FOR DETERMINING THE FLEXURAL STRENGTH OF CERTIFIED MATERIALS USING THREE-POINT LOADING (25)

UIG-101.1 Scope

This test method outlines the determination of the flexural strength of Certified Material, as required by UIG-84, using a simple beam in three-point loading at room temperature. This method is restricted to tubes.

UIG-101.2 Terminology

For definitions relating to certified materials, see UIG-3.

flexural strength: a measure of the ultimate load capacity of a specified beam in bending.

UIG-101.3 Apparatus

(a) The three-point loading fixture shall consist of bearing blocks, which ensure that forces applied to the beam are normal and without eccentricity.

(b) The bearing block diameter shall be between $^1/_{10}$ and $^1/_{20}$ of the specimen support span. A hardened bearing block, or its equivalent, is necessary to prevent distortion of the loading member.

(c) The direction of loads and reactions may be maintained parallel by the use of linkages, rocker bearings, and flexure plates. Eccentricity of loading can be avoided

by the use of spherical bearings. Provision must be made in the fixture design for relief of torsional loading to less than 5% of the nominal specimen strength.

UIG-101.4 Test Specimen

(a) Size. The test specimen shall have a length to diameter ratio greater than or equal to 5 as shown in Figure UIG-101.4-1.

(b) Measurements. All dimensions shall be measured to the nearest 5%.

UIG-101.5 Procedure

(a) Center the load applying bearing surface and the test specimen on the bearing blocks. The support span shall be greater than or equal to five times the tube outside diameter.

(b) The load applying bearing surface shall make contact with the upper surface of the test specimen. Load and support bearing blocks must be parallel to each other and perpendicular to the test surface. Use a loading rate of 0.05 in./min. (1.3 mm/min.) or less on screw-driven testing machines. On other test devices load the specimen at a uniform rate such that fracture occurs in 5 sec or more.

UIG-101.6 Test Data Record

(a) Measurements to 0.001 in. (0.02 mm) shall be made to determine the average inside and outside diameters at the section of failure.

(b) The load at failure must be recorded to an accuracy of ±2% of the full-scale value.

UIG-101.7 Calculation

(a) Calculate the flexural strength as follows:

$$S = \frac{PLD_o}{8I}$$

and

$$I = \frac{\pi}{64}\left(D_o^4 - D_i^4\right)$$

where

D_i = inside diameter, in. (mm)
D_o = outside diameter, in. (mm)
I = moment of inertia, in.^{4} (mm^4)
L = support span length, in. (mm)
P = maximum applied load, lb (N)
S = flexural strength, psi (MPa)

(b) If fracture occurs in less than 5 sec, the results shall be discarded but reported.

UIG-101.8 Report

(a) The report of each test shall include the following:

(1) specimen identification

(2) average outside diameter to the nearest 0.001 in. (0.02 mm)

(3) average inside diameter to the nearest 0.001 in. (0.02 mm)

(4) span length, in. (mm)

(5) rate of loading, in./min (mm/min)

(6) maximum applied load, lb (N)

(7) flexural strength calculated to the nearest 10 psi (0.1 MPa)

(8) defects in specimen

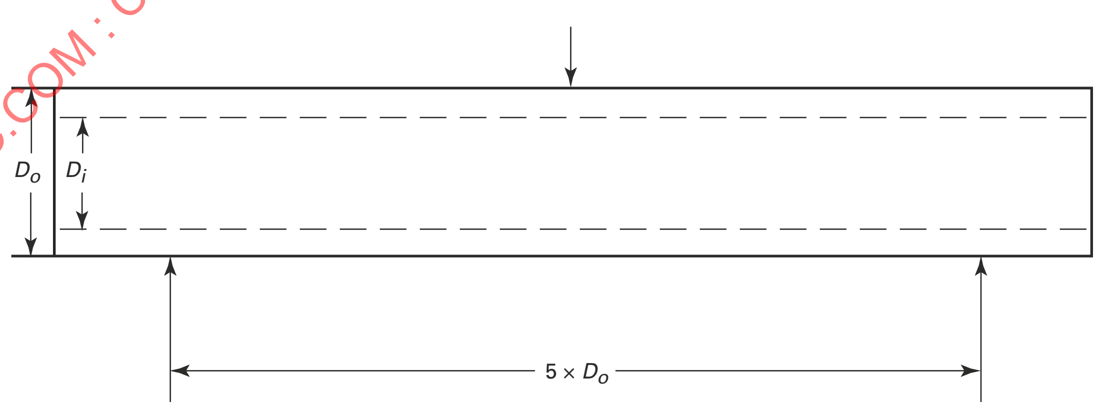
(9) failure mode and location

UIG-102 STANDARD TEST METHOD FOR DETERMINING THE TENSILE STRENGTH OF CERTIFIED MATERIALS (25)

UIG-102.1 Scope

This test method outlines the method of determination of the tensile strength of Certified Carbon and Graphite Materials, as required by UIG-84, using cylindrical or rectangular specimens at designated temperature.

Figure UIG-101.4-1
Test Specimen Arrangement



UIG-102.2 Terminology

For definitions relating to certified materials, see UIG-3.

tensile strength: a measure of the ultimate load capacity, resistance to elongation, measured in the longitudinal length of the material.

UIG-102.3 Apparatus

(a) The testing machine shall have a load measurement capacity such that the breaking load of the test specimen falls between 10% and 90% of the scale capacity. This range must be linear to within 1% over 1% increments. The requirements of the machine shall conform to the practices of the ASTM E4. Standard Practices for Force Verification of Testing Machines.

(b) The percent error for forces within the range of forces of the testing machine shall not exceed ±1%. Repeatability errors shall not be greater than 1%.

UIG-102.4 Test Specimens

(a) Preparation. The test specimens shall be prepared to the configurations shown in Figures UIG-76-1 through UIG-76-6.

(b) Fracture Zone. The acceptable fracture zone of the specimens shall be as shown in Figures UIG-76-1 through UIG-76-6.

(c) Measurements. To determine the cross-sectional area, the diameter, or width and thickness, of the specimen at the narrowest point shall be used. These dimensions shall be recorded to the nearest 0.001 in. (0.02 mm).

(d) Orientation. The specimen shall be marked on the end to denote its (grain) orientation with respect to the parent stock.

UIG-102.5 Procedure

(a) Load Applier. Center the test specimen in the load applying, gripping devices.

(b) Speed of Testing. Test speed shall be defined in terms of free running.

The speed shall be 0.020 in. ± 10% (0.508 mm ± 10%) per min.

UIG-102.6 Test Data Record

(a) Measurement to 0.001 in. (0.02 mm) shall be made to determine the average gage diameter, or width and thickness, of the specimen in the region of the fracture zone.

(b) The load at failure shall be measured to an accuracy of ±1%.

(c) If any part of the fracture takes place outside of the acceptable fracture zone as defined in UIG-102.4(b), the test shall be discarded, but reported.

UIG-102.7 Calculations

(a) Calculate the tensile strength as follows:

$$S_t = \frac{P_{max}}{A}$$

where

A = smallest cross-sectional area within the fracture zone, in.^{2} (mm^2)
P_{max} = maximum applied load, lb (N)
S_t = tensile strength, psi (MPa)

(b) The cross-sectional area is given by the following equations:

(1) For cylindrical specimens:

$$A = \frac{\pi D^2}{4}$$

where

D = minimum diameter of the gage section of the specimen, in. (mm)

(2) For rectangular specimens:

$$A = b \times h$$

where

b = width of cross section, in. (mm)
h = thickness of cross section, in. (mm)

UIG-102.8 Reports

(a) The report of each test shall include the following:

(1) specimen identification

(2) minimum gage diameter, or width and thickness, to the nearest 0.001 in. (0.02 mm)

(3) rate of loading

(4) maximum applied load

(5) tensile strength calculated to the nearest 10 psi (0.1 MPa)

(6) defects in specimens

(7) orientation of specimen, with or against the grain

(8) failure mode and location

(9) test temperature of specimens

UIG-103 STANDARD TEST METHOD FOR DETERMINING THE COMPRESSIVE STRENGTH OF CERTIFIED MATERIAL (25)

UIG-103.1 Scope

(a) This test method covers the determination of the compressive strength of impervious carbon and graphite at room temperature.

(b) This Standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this Standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

UIG-103.2 Referenced Documents

ASTM C709, Standard Terminology Relating to Manufactured Carbon and Graphite
ASTM E4, Standard Practices for Force Verification of Testing Machines
ASTM E177, Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods
ASTM E691, Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
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UIG-103.3 Terminology

See UIG-3 for definitions of terms related to manufactured impervious graphite.

UIG-103.4 Significance and Use

Impervious graphite can usually support higher loads in compression than in any other mode of stress. The compressive strength test, therefore, provides a measure of the maximum load-bearing capability of carbon and graphite objects.

UIG-103.5 Apparatus

(a) Test machine, conforming to Practice E4 and to the requirements for speed of testing prescribed in Section 8 of this test method.

(b) All load-bearing machine and fixture surfaces shall have a minimum hardness of 45 HRC and surface finish of 16 μin. (0.4 μm) rms maximum. Surfaces in contact with the specimen shall be flat to less than 0.0005 in./in. (0.0005 mm/mm).

(c) Examples of arrangements of the load train are shown schematically in ASTM C695, Figs. 1 and 2.

UIG-103.6 Sampling

Samples may be taken from locations and orientations that satisfy the objectives of the test.

UIG-103.7 Test Specimen

The test specimen shall be one of the following:

(a) a $^3/_4$ in. (19 mm) cube

(b) a flat circular disc with height equal to the disc O.D.

(c) a tube with height equal to the tube O.D.

The ends of all specimens shall be machined to yield planar and parallel faces. These faces shall be perpendicular to within 0.001 in. (0.02 mm) of a length total indicator reading. Reasonable care should be exercised to ensure that all edges are sharp and without chips or other flaws.

UIG-103.8 Procedure

(a) Center the specimen in the machine between the contact surfaces. The deviation of the specimen axis from the machine axis shall be less than 5% of the specimen length. Centering can be assisted by appropriate circles marked on the contact surfaces.

(b) Place an appropriate guard around the specimen to deflect flying fragments at failure.

(c) Apply the load continuously, and without shock until ultimate failure.

(d) If the test machine is equipped with a load or strain pacing device, a constant load or strain rate may be used.

UIG-103.9 Calculation

Calculate the compressive strength of each specimen as follows:

$$C = \frac{W}{A}$$

where

A = calculated area of the gage section of the specimen, in.^{2} (mm^2)
C = compressive strength of specimen, psi (MPa)
W = total load on the specimen at failure, lbf (N)

UIG-103.10 Report

The report shall include the following:

(a) type of testing machine, hydraulic or screw

(b) type and size of contact blocks

(c) general description of material being tested

(d) dimensions, location, and orientation of specimens

(e) details of specimen preparation

(f) rate of crosshead or platen movement, or load rate, or strain rate

(g) load of failure, failure mode, and compressive strength of each specimen, and material tested

(h) mean compressive strength and standard deviation for material tested

(i) test temperature of specimens

UIG-103.11 Precision and Bias

(a) *Precision*. The precision statements given in this section are based on the comparison of the mean strength by the Student t test and carrying out the statistical analysis of the data obtained in a round robin as recommended by Practice E 691. The round robin was carried out on two materials.

(b) Comparison of the Means. The comparison of the means by the Student's t test leads to the conclusion that the average strength values measured by each laboratory on each material is considered statistically equal at 95% confidence level.

(25) UIG-104 STANDARD TEST METHOD FOR DETERMINING THE COEFFICIENT OF PERMEABILITY OF CERTIFIED MATERIAL

UIG-104.1 Scope and Field of Application

The vacuum-decay method specified in this standard serves to determine the coefficient of permeability of test specimens made from carbon and graphite materials (solid matter) at room temperature. With this method using air as experimental gas, coefficients of permeability between about 10^1 and 10^{-9} in.^{2}/sec can be determined. The coefficient of permeability gives the admittance of gas through solid materials.

UIG-104.2 Concept

(a) Coefficient of Permeability

The coefficient of permeability *k(L)* is the volume of air flow through the test specimen divided by its cross section at a constant pressure difference.

$$k(L) = \frac{dV}{dt} p \frac{l}{A} \frac{1}{\Delta p}$$

where

A = the effective cross section of the test specimen in the direction of flow, in.^{2} (mm^2)

dV/dt = the volume airflow within a time period, in.^{3}/sec (mm^3/s)

l = the effective length of the test specimen in the direction of flow, in. (mm)

p = the average pressure $(p_a + p_i)/2$, psi (MPa) where

  p_a = the pressure of the air entering the test specimen

  p_i = the pressure of the air leaving the test specimen

Δp = the pressure difference $p_a - p_i$, psi (MPa)

(b) Vacuum-Decay Method

The vacuum-decay method uses air as experimental gas to measure the coefficient of permeability, *k(L)*, by determination of the pressure increase in a constant volume.

$$k(L) = \frac{dp_i}{dt} V \frac{l}{A} \frac{1}{\Delta p}$$

where

A = the effective cross section of the test specimen, in.^{2} (mm^2)

dp_i/dt = the rate of the pressure increase in the measuring volume within a time period

Δp = the average pressure difference, $p_a - p_i$, psi (MPa)

  p_a = the pressure of air entering the test specimen

  p_i = the pressure of air leaving the test specimen, to be calculated from $p_i = (p_{11} + p_{12})/2$, where

  p_{11} = the pressure of the air entering the test specimen at the beginning of the measurement

  p_{12} = the pressure of the air leaving the test specimen at the end of the measurement

V = the measuring volume, in.^{3} (mm^3). The measuring volume is the volume in which the pressure of air as experimental gas varies during the test. In the case of tubular test specimens, the measuring volume is the sum of the cavity volumes of the vacuum device and the test specimen. The pore volume of the test specimen is not taken into account.

UIG-104.3 Principle

In an evacuated measuring volume, which is separated from the outside air by the test specimen, the time dependent pressure increase caused by the inflowing air is determined. The coefficient of permeability is calculated from this pressure increase (vacuum-decay), from the pressure difference over the test specimen, the dimensions of the test specimen, and the measuring volume.

UIG-104.4 Apparatus

Vacuum apparatus (see schematic diagram in Figure UIG-104.4-1)

UIG-104.5 Specimens

Where tubular specimens are used, the surfaces to be sealed must be machined in a way that an efficient seal is guaranteed.

UIG-104.6 Procedure

Coefficient of permeability *k(L)* is the volume of air flow through the test specimen divided by its cross section at a constant pressure difference.

$$k(L) = \frac{\Delta p_i}{\Delta t} V \frac{\ln \frac{d_a}{d_i}}{2\pi l_2} \frac{1}{\Delta p}$$

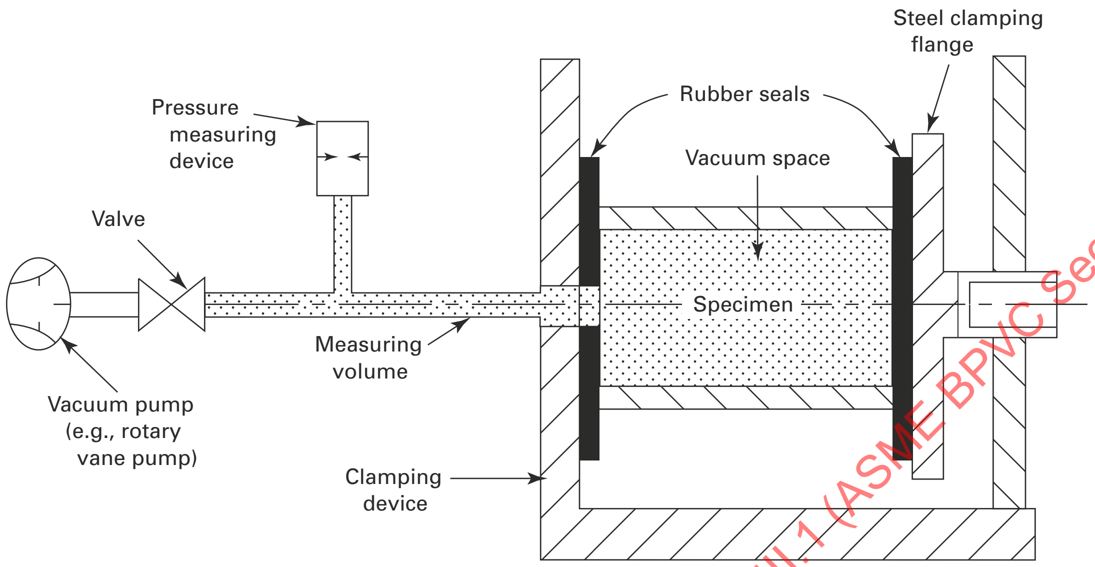
where

d_a = the outer diameter of the tube, in. (mm)

d_i = the inner diameter of the tube, in. (mm)

l_2 = the length of the tube, in. (mm)

Figure UIG-104.4-1
Schematic Diagram of Vacuum Apparatus



p_a = the pressure of the air entering the test specimen, psi (MPa)

p_i = $(p_{11} + p_{12})/2$, psi (MPa)

- p_{11} = the pressure of the air leaving the test specimen at beginning of measurement, time t_1
- p_{12} = the pressure of the air leaving the test specimen at end of measurement, time t_2

V = the measuring volume, in.^{3} (mm^3)

Δp = the pressure difference, $p_a - p_i$, psi (MPa)

Δp_i = the pressure difference, $p_{12} - p_{11}$, psi (MPa)

Δt = the period of time (measuring time), $t_2 - t_1$, sec

UIG-104.7 Test Report

The following shall be specified in the test report with reference to this Standard:

(a) type, number, and designation of specimens

(b) time for evacuation, and drying conditions

(c) pressures p_{11} and p_{12}

(d) measuring time

(e) coefficient of permeability *k(L)* of the specimens, in.^{2}/sec (mm^2/s), written in powers of 10, rounded to the nearest 0.1 in.^{2}/sec [for example, $k(L)$ = 0.015 in.^{2}/sec, written as $k(L) = 1.5 \times 10^{-2}$ in.^{2}/sec (2.3×10^{-5} mm^2/s)], as

(1) individual values

(2) mean value

(f) agreed conditions deviating from this Standard

(g) test date

UIG-104.8 Precision

The relative uncertainty of the measurement is about 10%.

UIG-105 STANDARD TEST METHOD FOR DETERMINING THE COEFFICIENT OF THERMAL EXPANSION OF CERTIFIED MATERIAL (25)

UIG-105.1 Scope

This method shall be used to determine thermal expansion factors for

(a) characterization of material with the grain direction (W.G.) and against the grain (A.G.)

(b) thermal or mechanical calculation in material application

UIG-105.2 Test Method

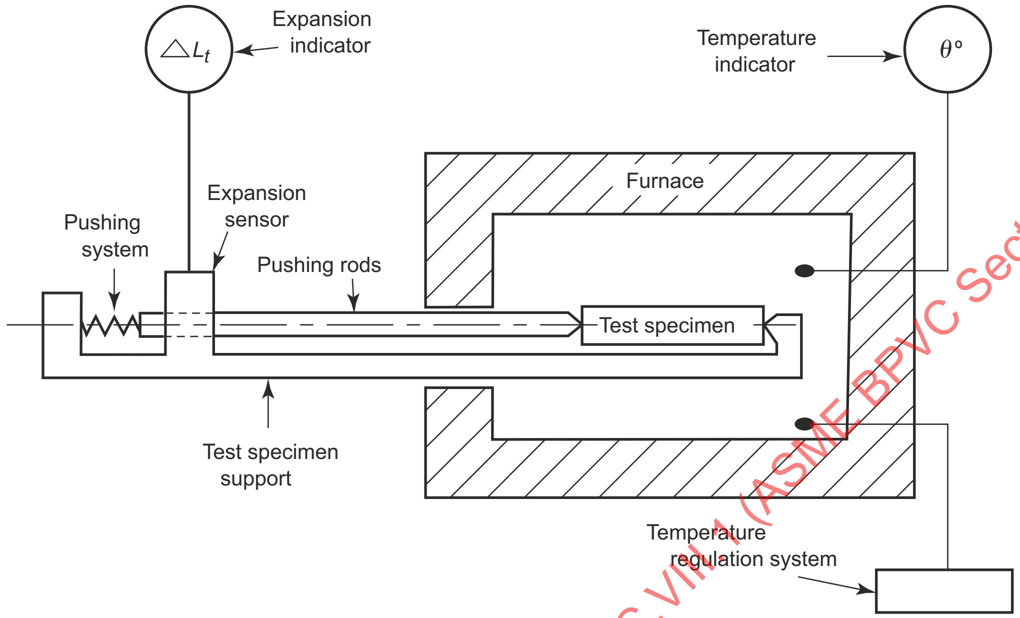
The method gives minimum requirements for determination of real expansion of material under temperature effect, depending on used equipment, test specimen, testing processing, and subsequent calculations.

UIG-105.3 Equipment

(a) Typical equipment (Dilatometer) for determination of material thermal expansion is described in Figure UIG-105.3-1.

(b) Material used for pushing rods and support must be the same. The thermal expansion factor of this material must be determined in the range of applicable temperature measurement. This material must have a significantly smaller value of thermal expansion factor than the tested material to improve the accuracy of results.

Figure UIG-105.3-1
Typical Equipment (Dilometer) for Thermal Expansion Test



(c) The equipment must be calibrated, according to the Manufacturer's recommended practice.

UIG-105.4 Test Specimen

(a) The size of specimen is in accordance with the ability of used equipment and manufacturer's recommendation.

(b) The section must be regular all along the specimen length, the end parts are to be parallel, with good finished surfaces to allow efficient contact to measuring touch.

(c) The test specimen is identified to grain direction and material grade and impregnation type, if any.

UIG-105.5 Testing Process

(a) Testing Parameters

v = heating rate, less than 90°F/hr (50°C/h)
ΔL_t = recorded expansion, in. (mm)
θ_o = the initial temperature of the material, assumed to be room temperature, 72°F ± 4°F (22°C ± 2°C)
θ_M = maximum test temperature, typically 36°F (20°C) over θ_m
θ_m = maximum design temperature for the material to be tested, °F (°C)

(b) Positioning of cleaned specimen into the support with minimum allowable pressure contact

(c) Recording of test curve $\Delta L_t = f(\theta)$

UIG-105.6 Thermal Expansion Factor

The following thermal expansion factors may be determined after test:

(a) Linear average factor from θ_o to $\theta_m = \alpha_{om}$, °F^{-1} (°C^{-1})

(b) Factor at $\theta_m = \alpha_m$, °F^{-1} (°C^{-1})

Graphic use of recording curve is given in Figure UIG-105.6-1.

UIG-105.6.1 Linear Average Factor From θ_o to θ_m.

(a) Expansion Parameters

L_O = original length of test specimen, in. (mm)
$\Delta L_{r\theta}$ = recorded expansion at 4°F (2°C), in. (mm) interval
$\Delta L_{s\theta}$ = expansion of specimen supports at 4°F (2°C) interval, in. (mm), according to equipment manufacturer's procedure
ΔL_θ = material expansion at 4°F (2°C), in. (mm)

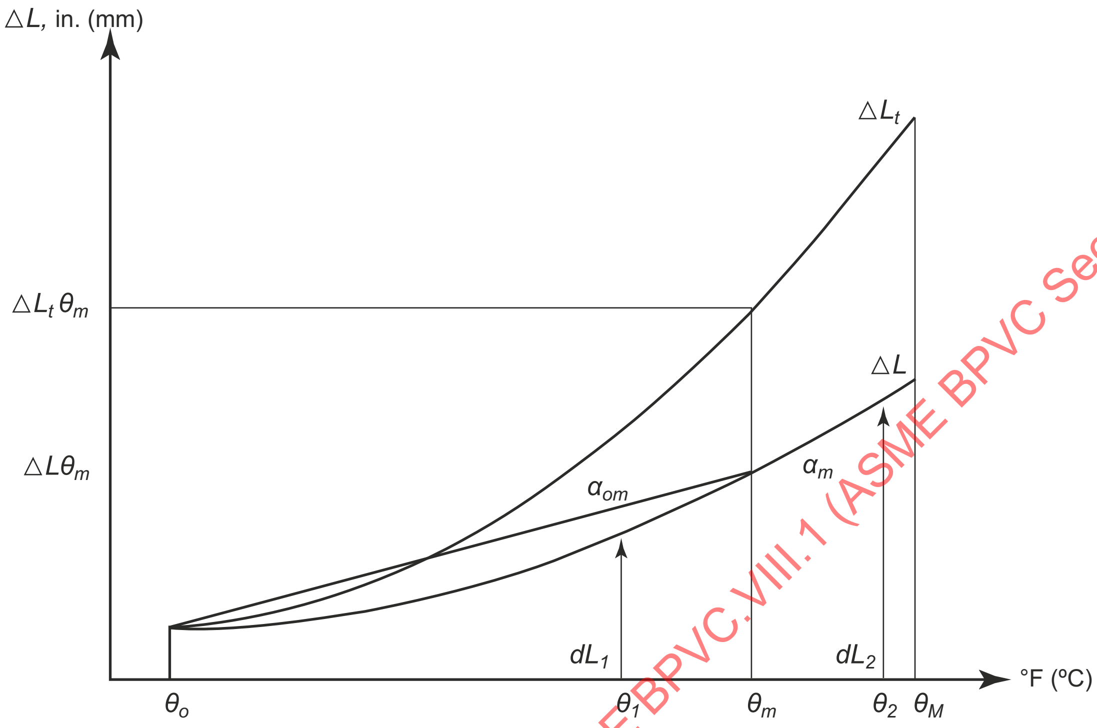
(b) Calculation

The material expansion at 4°F (2°C) intervals shall be determined as follows:

$$\Delta L_\theta = \Delta L_{r\theta} - \Delta L_{s\theta}$$

$$\frac{\Delta L_\theta}{L_o} = \frac{\Delta L_{r\theta}}{L_o} - \frac{\Delta L_{s\theta}}{L_o}$$

Figure UIG-105.6-1
Typical Recording Curve in Thermal Expansion Test, $\Delta L_t = f(\theta)$



$$\alpha_{om} = \frac{\Delta L_\theta / L_o}{\theta_o - \theta_m}, °F^{-1}\left(°C^{-1}\right)$$

UIG-105.6.2 Factor at θ_m.

(a) This factor is given by the slope of a tangent line to the material expansion curve on θ_m point.

(b) This factor may be determined by graphic construction as indicated on Figure UIG-105.6-1.

$$\alpha_m = \frac{dL_2 - dL_1}{2 d\theta L_o}, °F^{-1}\left(°C^{-1}\right)$$

where

dL_1 = obtained by construction on θ_1 point
dL_2 = obtained by construction on θ_2 point
$d\theta$ = $(\theta_M - \theta_m)$, °F (°C)
θ_1 = $(\theta_M - d\theta)$, °F (°C)
θ_2 = $(\theta_m + d\theta)$, °F (°C)

UIG-105.6.3 Report. The following information shall be included in the report:

(a) identification of test and recording

(b) type of equipment-support and pushing rod material, pushing level

(c) test specimen dimensions, material grade/impregnation, grain direction

(d) heating rate, origin and maximal operating temperature

(e) test results α_{0m} and α_m; usually in E^{-6}, °F^{-1} (°C^{-1}) unit

(f) name, title, and date

UIG-112 QUALITY CONTROL REQUIREMENTS

The Manufacturer's quality control manual shall, in addition to the provisions of Mandatory Appendix 10, include the following:

(a) The Authorized Inspector may, with cause, call for the requalification of procedures and personnel.

(b) The Manufacturer shall include sufficient provision for material control to ensure that all material is traceable to the manufacturing lot number. The Manufacturer shall maintain traceability of all materials used in construction of vessels and vessel parts until such time that the Manufacturer's Data Report has been completed and the Certification Mark applied.

UIG-115 MARKINGS AND REPORTS

The provisions of UG-115 through UG-120 shall apply to complete graphite pressure vessels or parts except as modified in UIG-116 through UIG-121.

(25) UIG-116 REQUIRED MARKINGS

(a) Each graphite pressure vessel and graphite pressure vessel part requiring inspection under this Part shall be marked in accordance with the requirements of UG-116 except as modified herein.

(b) The type of construction shall be indicated directly below the Certification Mark and U or PRT VIII-1 Designator by applying the letter "G" [see UG-116(b)(1)].

(c) The stamping may be applied to metallic parts, a nameplate, or a permanent impression on the graphite using cement (see Nonmandatory Appendix UIG-B). Nameplates may be attached to either metallic or graphite parts.

(d) For multiple identical items from a single lot, such as tubes, the Manufacturer shall apply the partial stamping nameplate to the bundle or container. Each piece shall be identified by permanent marking with the Manufacturer's name, date, and serial number. (A coded marking system with traceability of these data is acceptable.) The subsequent Manufacturer shall maintain the nameplate until all of the multiple pieces have been used, and shall then obliterate the Certification Mark with the U or PRT VIII-1 Designator from the nameplate. Obliteration of the Certification Mark with the U or PRT VIII-1 Designator stamping shall be witnessed by the Authorized Inspector.

NOTE: Permanent shall mean any method of marking that will ensure that the marking is present until the item is incorporated into a completed vessel, and the Authorized Inspector has signed the data report.

(e) A Manufacturer with multiple locations, each holding its own Certificate of Authorization, may transfer graphite pressure vessels or pressure vessel parts from one of its locations to another of its locations without certification stamping, provided the Quality Control System of each location describes the method of identification, transfer, receipt, and inspection of the parts. These methods shall include the following requirements:

(1) Identification requirements shall include details of the specific marking to be applied. Identification shall be on each part and shall be legible, permanent, and not detrimental to the part.

(2) The Certificate Holder shall have a transmittal form that is included with each transfer. The transmittal form shall list all items with corresponding identification numbers, with indication that the items do not contain the Certification Mark. This form shall be signed by the Certificate Holder.

(3) Qualified inspection personnel at the receiving location shall inspect each item upon receipt.

(4) The Manufacturer of the completed vessel shall retain all transfer forms as part of the vessel records; see Mandatory Appendix 10, 10-13.

(f) A supplemental tag or marking shall be applied to the pressure vessel to caution the user of any restrictions on the design, testing, or operation of the pressure vessel. The supplemental tag or marking shall meet the requirements of UG-118 or UG-119, except that the height of the characters shall be at least $^1/_8$ in. (3 mm). Graphite shell-and-tube heat exchangers with springs shall be marked with the following supplemental marking:

CAUTION: The heat exchanger design has been evaluated for the range of conditions listed on Form U-5B. It shall be reevaluated for conditions outside this range before being operated at them.

UIG-120 DATA REPORTS (25)

(a) Nonmandatory Appendix W, Form U-1B, Manufacturer's Supplementary Data Report for Graphite Pressure Vessels, shall be completed and certified by the Manufacturer, and shall be signed by the Authorized Inspector for each graphite pressure vessel or part marked with the Certification Mark with the U or PRT VIII-1 Designator. Nonmandatory Appendix W, Form U-1B shall be completed as otherwise required for Data Reports as specified in UG-120.

(b) Nonmandatory Appendix W, Form U-1B shall be attached to and referenced on the applicable Data Report specified in UG-120.

(c) A Manufacturer with multiple locations, each holding its own Certificate of Authorization, may transfer graphite pressure vessels or pressure vessel parts from one of its locations to another of its locations without Partial Data Reports provided the Quality Control System of each location describes the method of identification, transfer, receipt, and inspection of the parts. These methods shall include the requirements of UIG-116(e)(1) through UIG-116(e)(4).

(d) For graphite shell-and-tube heat exchangers with springs, each design and operating condition shall be indicated on Form U-5B (see Nonmandatory Appendix W). The operating conditions may be combined on this form where they are bounded by the operating pressure range, maximum component temperatures, and axial differential thermal expansion range. The following data shall be listed for each condition:

(1) Name of Condition. The first condition shown shall be the design condition. If there is more than one design condition or a differential pressure design condition, multiple lines may be used. Each different operating condition or range of operating conditions shall be listed.

(2) Design/Operating Pressure Ranges. The range of shell side and tube side pressures for each condition shall be listed.

(3) Design/Operating Component Temperatures. For each condition, the design basis temperatures for the shell and tubes shall be listed. Any component temperature between the MDMT and the listed temperature is permitted, provided the resulting axial differential thermal expansion is within the listed range.

(4) Axial Differential Thermal Expansion Range. The minimum and maximum axial differential thermal expansion, Y [see UIG-34(b)(5), Step 5], for each operating

condition shall be listed. If the calculated axial differential thermal expansion is positive, zero shall be used for the minimum value and the actual calculated value shall be used as the maximum value. If the calculated axial thermal expansion differential is negative, the calculated value shall be used as the minimum value and zero shall be used as the maximum value. Within the listed range of operating temperature and pressure, any combination of shell and tube axial mean component temperatures is permitted, provided the resulting axial differential thermal expansion is within the listed range.

UIG-121 RECORDS (25)

The Manufacturer shall maintain records of the procedures employed in fabricating vessels and vessel parts and in cementing parts together. The Manufacturer shall also maintain records of the tests and their results by which the Procedure Specifications were qualified for fabrication. The Manufacturer shall maintain the records of design calculations, certified material test reports, visual examination, the procedure specifications that detail the materials used, fabrication procedures and quality control records. All records shall be dated and shall be certified by the Manufacturer and made available to the Authorized Inspector. The Manufacturer shall keep these records on file for at least 5 yr.

(25)

FORM CMQ CERTIFIED MATERIAL QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels)

Certified material qualification no. ____________________

Qualification of certified material specification (CMS) no. ____________________

Certified material manufacturer ____________________ Date __________

Materials:

Raw material manufacturer ____________________

Material ____________________

Grade ____________________

Specification no. ____________________

Impregnation agent manufacturer ____________________

Material ____________________

Grade ____________________

Specification no. ____________________

GENERAL NOTE: Test program to certify requirements per Table UIG-6-1.

	Block	Tube
Tensile strength at room temperature	10 test samples __________	10 test samples __________
Tensile strength at maximum allowable material temperature after 1 hr exposure	10 test samples __________	10 test samples __________
Flexural strength at room temperature	N/A	10 test samples __________
Compressive strength room temperature	10 test samples __________	10 test samples __________
Compressive strength at maximum allowable material temperature after 1 hr exposure	10 test samples __________	10 test samples __________
Coefficient of permeability at room temperature	10 test samples __________	10 test samples __________
Coefficient of thermal expansion	10 test samples __________	10 test samples __________

NOTES:

(1) All graphite block tensile and compressive samples are tested across grain, and all tube samples are tested with grain.

(2) Test results shall meet the requirements of Table UIG-6-1 as applicable.

Certified by ____________________ Date __________

(07/25)

FORM CMQ CERTIFIED MATERIAL QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

TEST PROCEDURES AND RESULTS

(a) Flexural strength: See the test method for determining the flexural strength of certified materials using three point loading in UIG-101.

1. Test performed at ______________________________

By ______________________________ Date ______________

	Flexural Strength, psi (MPa)
Sample No.	**Tube**
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average value	
Test deviation in % from average value	
Permissible deviation	±20%

(07/25)

FORM CMQ CERTIFIED MATERIAL QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(b) Tensile Strength: See the test method for determining tensile strength of certified materials in UIG-102.

(1) Figure UIG-76-1 Block
Figure UIG-76-5 Tubes

(2) Test Performed at ______________________________

By ______________________________ Date ______________

	Tensile Strength, psi (MPa)			
	Room Temperature		Maximum Material Temperature	
Sample No.	Block	Tube	Block	Tube
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Average value				
Test deviation in % from average value				
Permissible deviation	±20%	±20%	±20%	±20%
UIG-6, minimum value, psi (MPa)	2,000 (13.8)	2,000 (13.8)	N/A	N/A

(07/25)

FORM CMQ CERTIFIED MATERIAL QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(c) Compressive Strength: See the test method for determining compressive strength of certified materials in UIG-103.

(1) Test performed at ______________________________

By ______________________________ Date __________

	Compressive Strength, psi (MPa)			
	Room Temperature		Maximum Material Temperature	
Sample No.	Block	Tube	Block	Tube
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Average value				
Test deviation in % from average value				
Permissible deviation	±20%	±20%	±20%	±20%
UIG-6, minimum value, psi (MPa)	6,500 (45)	6,500 (45)	N/A	N/A

(07/25)

FORM CMQ CERTIFIED MATERIAL QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(d) Coefficient of Permeability: See the test method for determining coefficient of permeability of certified material in UIG-104.

(1) Test performed at ______________________________

By ______________________________ Date __________

	Permeation Rate in in.^{2}/sec (mm^2/s)	
Sample No.	**Block**	**Tube**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
UIG-6, maximum value	4.5×10^{-6} in.^{2}/sec (2.90×10^{-3} mm^2/s)	4.5×10^{-6} in.^{2}/sec (2.90×10^{-3} mm^2/s)

(07/25)

FORM CMQ CERTIFIED MATERIAL QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(e) Coefficient of Linear Thermal Expansion: See the test method for determining the coefficient of thermal expansion of certified material in UIG-105.

(1) Test temperature: room temperature to 300ºF (149ºC)

(2) Test performed at ______________________________

By ______________________________ Date __________

	Coefficient of Thermal Expansion (in./in.-°F)	
Sample No.	Block	Tube
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

(07/25)

FORM CMQ CERTIFIED MATERIAL QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

Record of Qualification Results

CMS no. ______________________________

CMQ no. ______________________________

(1) Physical properties at room temperature:

Physical Properties		Value
Flexural strength, tube	psi (MPa)	
Tensile strength, block	psi (MPa)	
Tensile strength, tube	psi (MPa)	
Compressive strength, block	psi (MPa)	
Compressive strength, tube	psi (MPa)	
Coefficient of permeability	in.^{2}/sec (mm^2/s)	
Coefficient of thermal expansion	in./in./°F (mm/mm/°C)	

(2) Maximum material temperature for this certified material ____________

(3) Change in strength over temperature range:

The strength variation value shall be considered linear between room temperature and the maximum material temperature. This value is determined by dividing the change in strength from ambient to maximum material temperature by the difference in temperature.

For this certified material the tensile strength variation value is ___ psi/°F (MPa/°C) rise above room temperature. This value may be positive or negative.

For this certified material the compressive strength variation value is ___ psi/°F (MPa/°C) rise above room temperature. This value may be positive or negative.

(4) Strength relationship between tensile, flexural, and compressive strength:

Flexural strength ______________ psi (MPa) (tubes only)

Tensile strength ______________ psi (MPa)

Compressive strength __________ psi (MPa)

(5) Correlation factors: Flexural strength / tensile strength ______________________________

(Tubes only) Flexural strength / compressive strength ______________________________

(07/25)

(25)

FORM CMQ-C CERTIFIED MATERIAL QUALIFICATION FORM — COMPOUND MATERIAL
(Used in the Construction of Graphite Pressure Vessels)

Certified material qualification no. ______________________________

Qualification of certified material specification (CMS) no. ______________________________

Certified material manufacturer ______________________________ Date ____________

Materials:

Graphite material manufacturer ______________________________

Material ______________________________

Grade ______________________________

Specification no. ______________________________

Binder system materials manufacturer ______________________________

Material ______________________________

Grade ______________________________

Specification no. ______________________________

GENERAL NOTE: Test program to certify requirements per Table UIG-6-1.

	Block	Tube
Tensile strength at room temperature	10 test samples __________	10 test samples __________
Tensile strength at maximum allowable material temperature after 1 hr exposure	10 test samples __________	10 test samples __________
Flexural strength at room temperature	N/A	10 test samples __________
Compressive strength room temperature	10 test samples __________	10 test samples __________
Compressive strength at maximum allowable material temperature after 1 hr exposure	10 test samples __________	10 test samples __________
Coefficient of permeability at room temperature	10 test samples __________	10 test samples __________
Coefficient of thermal expansion	10 test samples __________	10 test samples __________
Modulus of elasticity	10 test samples __________	10 test samples __________
Modulus of elasticity at maximum allowable material temperature after 1 hr exposure	10 test samples __________	10 test samples __________

NOTE:

(1) Test results shall meet the requirements of Table UIG-6-1 as applicable.

Certified by ______________________________ Date ____________

(07/25)

FORM CMQ-C CERTIFIED MATERIAL QUALIFICATION FORM — COMPOUND MATERIAL
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(a) Tensile Strength: See the test method for determining tensile strength of certified materials in UIG-102.

(1) Figure UIG-76-6 Compound

(2) Test Performed at ______________________________

By ______________________________ Date ______________

	Tensile Strength, psi (MPa)			
	Room Temperature		Maximum Material Temperature	
Sample No.	Block	Tube	Block	Tube
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Average value				
Test deviation in % from average value				
Permissible deviation	±20%	±20%	±20%	±20%
UIG-6, minimum value, psi (MPa)	1,500 (10.3)	1,500 (10.3)	N/A	N/A

(07/25)

FORM CMQ-C CERTIFIED MATERIAL QUALIFICATION FORM — COMPOUND MATERIAL
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(b) Compressive Strength: See the test method for determining compressive strength of certified materials in UIG-103.

(1) Test performed at ______________________________

By ______________________________ Date __________

	Compressive Strength, psi (MPa)			
	Room Temperature		Maximum Material Temperature	
Sample No.	Block	Tube	Block	Tube
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Average value				
Test deviation in % from average value				
Permissible deviation	±20%	±20%	±20%	±20%
UIG-6, minimum value, psi (MPa)	4,500 (31)	4,500 (31)	N/A	N/A

(07/25)

FORM CMQ-C CERTIFIED MATERIAL QUALIFICATION FORM — COMPOUND MATERIAL (Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(c) Coefficient of Permeability: See the test method for determining coefficient of permeability of certified material in UIG-104.

(1) Test performed at ____________________

By ____________________ Date __________

	Permeation Rate in in.^{2}/sec (mm^2/s)	
Sample No.	**Block**	**Tube**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
UIG-6, maximum value	4.5×10^{-6} in.^{2}/sec (2.90×10^{-3} mm^2/s)	4.5×10^{-6} in.^{2}/sec (2.90×10^{-3} mm^2/s)

(07/25)

FORM CMQ-C CERTIFIED MATERIAL QUALIFICATION FORM — COMPOUND MATERIAL
(Used in the Construction of Graphite Pressure Vessels) (Cont'd)

(d) Coefficient of Linear Thermal Expansion: See the test method for determining the coefficient of thermal expansion of certified material in UIG-105.

(1) Test temperature: room temperature to 300ºF (149ºC)

(2) Test performed at ______________________________

By ______________________________ Date __________

	Coefficient of Thermal Expansion (in./in.-°F)	
Sample No.	Block	Tube
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

(07/25)

FORM CMQ-C CERTIFIED MATERIAL QUALIFICATION FORM — COMPOUND MATERIAL (Used in the Construction of Graphite Pressure Vessels) (Cont'd)

Record of Qualification Results

CMS no. ______________________________

CMQ no. ______________________________

(1) Physical properties at room temperature:

Physical Properties		Value
Tensile strength, block	psi (MPa)	
Tensile strength, tube	psi (MPa)	
Compressive strength, block	psi (MPa)	
Compressive strength, tube	psi (MPa)	
Coefficient of permeability	in.^{2}/sec (mm^2/s)	
Coefficient of thermal expansion	in./in./°F (mm/mm/°C)	
Modulus of elasticity	psi (MPa)	

(2) Maximum material temperature for this certified material ___________________

(3) Change in strength over temperature range:

The strength variation value shall be considered linear between room temperature and the maximum material temperature. This value is determined by dividing the change in strength from ambient to maximum material temperature by the difference in temperature.

For this certified material the tensile strength variation value is ___ psi/°F (MPa/°C) rise above room temperature. This value may be positive or negative.

For this certified material the compressive strength variation value is ___ psi/°F (MPa/°C) rise above room temperature. This value may be positive or negative.

(07/25)

(25)

FORM CCQ CERTIFIED CEMENT QUALIFICATION FORM
(Used in the Construction of Graphite Pressure Vessels)

Certified cement qualification (CCQ) no. ____________________

Qualification of certified material specification (CCS) no. ____________________

Cementing technician ____________________ (Name) ____________________ (Mark or Symbol No.) ____________________ (Date)

Cement:

Manufacturer ____________________ (Name) ____________________ (Mark or Symbol No.) ____________________ (Date)

Designation ____________________

Joint configuration

BLOCK JOINT Figure UIG-76-2 (10 samples)
(Drawing #)

Testing:

(a) Test results shall meet the requirements of Table UIG-6-1.
(b) The qualification results shall be recorded.

	Tested Tensile Strength, psi (MPa)	
Sample No.	**At Room Temperature**	**At Maximum Material Temperature**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average, psi (MPa)		
Test deviation in % from average value		
Permissible deviation	±20%	±20%
UIG-6, minimum value, psi (MPa)	1,500 (10.3)	N/A

Certified by ____________________ Date ____________________

(07/25)

FORM CCQ CERTIFIED CEMENT QUALIFICATION FORM (Cont'd)

Essential Variables:

	Filler Material	Resin	Accelerator
Composition (% by weight)			
Material			
Curing conditions	____________________ minutes @ ____________________ °F (°C)		

(07/17)

(25)

FORM CPQ CEMENTING PROCEDURE QUALIFICATION FORM

Cementing procedure specification (CPS) no. ______________________________
(A change in any essential variable requires a new CPS)

Cement ______________________________
(Manufacturer and I.D. No.)

Joint configuration ______________________________
(Drawing No.)

Specimen for Tensile Test of Cemented Joints:

Block material joint:	Figure UIG-76-2: 10 samples
Tube-to-tubesheet joint:	Figure UIG-76-3: 5 samples
Tube-to-tube joint:	Figure UIG-76-4: 5 samples

Cementing Technician:

____
(Name) (Mark) (Report No.) (Date)

Cementing Operation:

(a) Surface preparation per drawing of specimen ______________________________

(b) Cement preparation per instruction no. ______________________________

(c) Cementing instruction no. ______________________________

(d) Treatment after cementing per instruction no. ______________________________

Inspection of Test Specimen:

Visual examination per instruction no. ______________________________

Test Results:

Tensile strength of cemented joints per ______________________________

Test temperature: Room temperature

Sample quantity: ____________ Per Figure ______________________________

Load speed: Per UIG-102

Certified by ______________________________ Date ______________________________

(07/25)

FORM CPQ CEMENTING PROCEDURE QUALIFICATION FORM (Cont'd) (Back)

	Tensile Strength, psi (MPa)		
Sample No.	Block Joint	Tube-to-Tubesheet Joint	Tube-to-Tube Joint
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Average value			
Test deviation in % from average value			
Permissible deviation, %	±20%	±20%	±20%
UIG-6, minimum tensile strength of cemented joints	1,500 (10.3)	1,500 (10.3)	1,500 (10.3)

(07/25)

FORM CTQ CEMENTING TECHNICIAN QUALIFICATION FORM
(Used in Cementing Parts of Graphite Pressure Vessels)

Name of technician ______________________________

Cementing procedure specification (CPS) no. ______________________________

Sample No.	Tensile Strength, psi (MPa)
1	
2	
3	
4	
UIG-6, minimum value	1,500 psi (10.3 MPa) (See Figure UIG-76-2)

Test report no. ______________________________

We certify that the statements made in this report are correct:

Date ______________ Signed ______________________________
(Manufacturer's representative)

(07/21)

NONMANDATORY APPENDIX UIG-A GUIDE TO PART UIG CERTIFICATION REQUIREMENTS

(25)

UIG-A-1 GENERAL

The purpose of this Appendix is to serve as a quick reference guide that can be used in conjunction with Part UIG to assist Manufacturers and summarize the requirements to manufacture Certified Material and graphite pressure vessels.

UIG-A-2 MATERIAL QUALIFICATION

(a) Prepare a Certified Material Specification (CMS) form for each grade of Certified Material.

(1) See UIG-77 for required information for the CMS form.

(2) See UIG-3 for raw material definitions and limitations.

(b) Prepare a Certified Cement Specification (CCS) form for each cement material to be used in Certified Material Manufacturing. See UIG-78 for required information for Form CCS.

(c) Prepare Certified Material Qualification (CMQ) form (s) for each Certified Material. See Form CMQ.

(1) See UIG-77 for the essential variables and other requirements for Form CMQ.

(2) See Table UIG-6-1 for Certified Material minimum strength requirements.

(3) See UIG-101 for flexural testing standard.

(4) See UIG-102 for tensile testing standard. See Figures UIG-76-1 through UIG-76-6 for test specimen requirements.

(5) See UIG-103 for compressive testing standard.

(6) See UIG-104 for coefficient of permeability testing standard.

(7) See UIG-105 for coefficient of thermal expansion testing standard

(8) All tests to be performed for Certified Material Qualification require 10 test specimens each.

(d) Prepare a Certified Cement Qualification (CCQ) form for Certified Cement Material. See Form CCQ.

(1) See UIG-78 for the essential variables and other requirements for Form CCQ. See UIG-102 for tensile testing standard.

(2) See Figure UIG-76-2 for test specimen requirements

(3) All tests to be performed for Certified Cement Qualification require 10 test specimens each.

UIG-A-3 CEMENTING PROCEDURE AND CEMENTING TECHNICIAN QUALIFICATION

(a) Prepare a Cementing Procedure Specification (CPS) for each Certified Cementing Procedure. See UIG-79 for required information for Form CPS.

(b) Prepare a Cementing Procedure Qualification (CPQ) form for each Certified Cementing Procedure. See Form CPQ.

(1) See UIG-79 for essential variables and other requirements for Form CPQ.

(2) See UIG-102 for tensile testing standard. See Figures UIG-76-2, UIG-76-3 , and UIG-76-4 for required test specimens.

(3) All tests to be performed for Cementing Procedure Qualification require 10 test specimens each.

(c) Prepare a Cementing Technician Qualification (CTQ) form for each individual that will be performing Certified Cementing Procedures. See Form CTQ.

(1) See UIG-80 for Cementing Technician Qualification requirements.

(2) See UIG-102 for tensile testing standard. See Figure UIG-76-2 for test specimen requirements.

(3) All tests to be performed for Cementing Technician Qualification require 4 test specimens each.

(d) Upon Qualification, each Cementing Technician shall be assigned an identifying number, letter, or symbol by the Manufacturer, which shall be used to identify the technician's work.

UIG-A-4 LOT TESTING

(a) For each lot (see UIG-3 for definition) of Certified Material, testing shall be performed to ensure that the recorded material properties remain consistent.

(1) See UIG-84 for Certified Material lot testing requirements.

(2) See Table UIG-84-1 for Certified Materials testing frequency requirements.

(3) See Table UIG-6-1 for the minimum values permitted for any single test specimen.

(4) All tests to be performed for Certified Material Lot testing require 5 test specimens each.

(b) Prepare a Certified Material Test Report (CMTR) for each Certified Material that is Lot tested. See UIG-6(b) for information required on all CMTR Forms.

UIG-A-5 DOCUMENTATION

(a) Specification Forms shall be created by the Manufacturer and shall contain, at a minimum, the information required per Part UIG.

(b) Qualification Forms are provided in Part UIG.

(c) Certified Material Test Reports (CMTR) shall be created by the manufacturer and shall contain, at a minimum, the information required per Part UIG.

(d) The Manufacturer shall maintain records of all Certified Material documentation as shown in UIG-121.

NONMANDATORY APPENDIX UIG-B ALTERNATIVE MARKING AND STAMPING OF GRAPHITE PRESSURE VESSELS

(25)

UIG-B-1 GENERAL REQUIREMENTS

(a) This procedure may be used to apply the Certification Mark to the graphite part.

(b) The required data as defined in UIG-116 shall be $^5/_{32}$ in. (4 mm) high, minimum.

(c) The Certification Mark stamp shall be used to make the impression in the cement.

UIG-B-2 APPLICATION OF THE CERTIFICATION MARK

(a) The graphite surface shall be clean and smooth.

(b) Apply a thin to medium coating of cement onto a small section of the Code part. The mixed cement should have a thick consistency (toothpaste).

(c) Apply heat to the cement so that it begins to form a skin (cement is still soft, not cured).

(d) Apply a thinned coat of a release agent (such as Antisieze) to the tip of the Certification Mark stamp.

(e) Before the cement hardens, firmly press the Certification Mark stamp into the cement all the way to the bottom, and pull the stamp straight out of the cement.

(f) Do not disturb the impression.

(g) Cure the impression as required.

(h) When cured, confirm that the impression is legible.

(i) The impression may be washed to remove excess release agent.

UIG-B-3 APPLICATION OF CHARACTERS DIRECTLY TO GRAPHITE

(a) Use a very thin template of a flexible material (e.g., stainless steel; flexible and easily cleaned).

(b) Place and hold the template over a clean smooth surface.

(c) Hold the template securely and trowel over with approved cement to fill all of the template area.

(d) Carefully lift the template from the graphite part and examine the detail of the characters.

(e) If the characters are incorrect or damaged, wipe off the cement with a compatible solvent and reapply.

(f) If acceptable, cure the cement.

(g) As an alternative to (a) through (f) above, the graphite surface may also be marked with a scribe or a tool.

NOTE: The preceding methods may be applied jointly to identify the graphite part and to transfer the Certification Mark stamp.

UIG-B-4 ACCEPTANCE CRITERION

The stamping must be legible and acceptable to the Authorized Inspector.

(25)

PART UJK
ELECTRICALLY HEATED OR GAS-FIRED JACKETED STEAM KETTLES

UJK-1 SCOPE

The rules in this Part provide additional requirements for electrically heated or gas-fired jacketed steam kettles constructed under the rules of this Division.

UJK-2 SERVICE RESTRICTIONS

No steam or water shall be withdrawn from the jacket for use external to the vessel and the operating pressure of the jacket shall not exceed 50 psi (350 kPa).

UJK-3 MATERIALS

When in contact with products of combustion, austenitic stainless steel parts shall be of either the low carbon or stabilized grades. Structural grade carbon steel, SA-36 and SA-283 (Grades C and D), shall not be used for any pressure part.

UJK-4 DESIGN

Welded Category A and B joints in contact with products of combustion shall be of Type No. 1 of Table UW-12.

UJK-5 INSPECTION AND STAMPING

Electrically heated or gas-fired jacketed steam kettles shall be inspected by an Inspector and shall not be marked with the Certification Mark with the UM Designator regardless of volume [see U-1(j)].

UJK-6 PRESSURE RELIEF

The capacity of the safety valve in pounds of steam per hour shall be at least equal to the Btu per hour rating of the burner divided by 1,000 or the kilowatt rating of the electric heating element multiplied by 3.5.

UJK-7 APPURTENANCES AND CONTROLS

The jacket shall be furnished with the following minimum appurtenances and controls [see U-2(a)(1)(-e)]:

(a) a pressure gage;

(b) a water gage glass; or alternatively, for electrically heated jacketed steam kettles with immersion type heating elements, a low level warning light;

(c) a separate connection, fitted with a stop valve, for venting air or adding water to the jacket (the water may be added while the vessel is not under pressure);

(d) an electric heater control or automatic gas valve controlled by pressure or temperature to maintain the steam pressure in the jacket below the safety valve setting;

(e) a low water cutoff that will cut off the fuel to the burner or power to the electric heating element if the water in the jacket drops below the lowest permissible water level established by the manufacturer;

(f) a safety pilot control that will cut off the fuel to both the main burner and the pilot burner in case of pilot flame failure.

UJK-8 DATA REPORTS

When all the requirements of this Division and the supplemental requirements of this Part have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance with Part UJK, Electrically Heated or Gas-Fired Jacketed Steam Kettles."

PART UJV JACKETED VESSELS

(25)

UJV-1 GENERAL

(a) The rules in this Part cover minimum requirements for the design, fabrication, and inspection of the jacketed portion of a pressure vessel.

(1) Design requirements for jacketed vessels in Section VIII, Division 2, 4.11 shall be used in lieu of those previously listed in Mandatory Appendix 9. Table UJV-1-1 lists the new locations for all requirements formerly located in this Division.

(2) The Division 1 design requirements listed in Table UJV-1-2 shall be used in lieu of the corresponding design requirements referenced in Division 2, 4.11.

(3) When a Mandatory Appendix 9 paragraph, table, or figure is referenced, the applicable section of Division 2 shall be used in accordance with UG-16(a) and Mandatory Appendix 46, except as indicated in Table UJV-1-2.

(4) Table UJV-1-3 lists the new locations in Division 2 for figures formerly located in Mandatory Appendix 9 that were referenced elsewhere in Division 1.

(b) Requirements other than design shall be in accordance with this Part.

(c) The rules in this Part cover the common jacket types but are not intended to limit configurations to those described herein. Designs that differ from those covered in this Part shall be in accordance with U-2(g).

(d) Where the internal design pressure is 15 psi (100 kPa) or less, and any combination of pressures and vacuum in the vessel and jacket will produce a total external pressure greater than 15 psi (100 kPa) on the inner vessel wall, the entire jacket shall be considered as within the scope of this Part.

(e) Half-pipe jackets are not within the scope of this Part. See Nonmandatory Appendix EE for half-pipe jackets.

(f) Dimpled jackets are not covered in this Part (see UW-19 or Part UDA).

(g) The requirements listed in Section VIII, Division 2, 4.11.3.3 are not applicable for design of closure member attachments to a pressure vessel.

(h) Where the inner vessel shall meet the requirements of UW-2, the attachment welds of the jacket to the inner vessel need not be welded for their full thickness nor radiographed. These attachment welds shall be postweld heat treated where required by UW-2 except as may be exempted by the Notes to Tables UCS-56-1 through UCS-56-11. The remainder of the jacket need not comply with UW-2 when the inner vessel alone is subjected to the service restrictions. The diameter limitations of UW-12 and UW-13 do not apply to the jacket attachment welds.

UJV-2 FABRICATION

(a) Fabrication of vessels shall be in accordance with applicable Parts of Subsection A and Subsection B, Part UW. The requirements of UW-13(e) do not apply to closure rings.

(b) This Part covers fabrication of jacketed vessels by welding. Other methods of fabrication are permitted, provided the requirements of applicable Parts of this Division are met.

(c) Where only the inner vessel is subjected to lethal service, the requirements of UW-2 shall apply only to welds in the inner vessel and those welds attaching the jacket to the inner vessel. Welds attaching the jacket to the inner vessel need not be radiographed and may be fillet welded. Postweld heat treatment shall be as required by Tables UCS-56-1 through UCS-56-11.

UJV-3 INSPECTION

Inspection and testing shall be carried out as stated in Subsection A.

Table UJV-1-1
Paragraph Cross-Reference List

2023 Division 1 Paragraph, Topic	Division 2
9-1, Scope	4.11.1
9-2, Types of jacketed vessels	4.11.1
9-4, Design of jacketed shell and jacketed head	4.11.2
9-5, Design of closure member of jacket to vessel	4.11.3
9-5, Symbols	4.11.7
9-6, Design of penetrations through jackets	4.11.4
9-7, Design of partial jackets	4.11.5

Table UJV-1-2
Division 2 Cross-Reference List to Division 1 Requirements

	Division 2		
Topic	Paragraph	Reference	Division 1
Loadings or design loads and load case combinations	4.11.2.1 and 4.11.4.3(a)	4.1	UG-22
Design rules for shells under internal pressure	4.11.2.1	4.3	UG-27 and UG-32
Design of shells under external pressure and allowable compressive stresses	4.11.2.1	4.4	UG-23, UG-28 to UG-30, and UG-33
Design rules for openings in shells and heads	4.11.1.3, 4.11.4.1(a), and 4.11.4.2	4.5	UG-36 to UG-43 and UG-45
Inspection openings	4.11.2.2	4.5.16	UG-46
Design rules for braced and stayed surfaces	4.11.2.4 and 4.11.5.2(a)	4.9	UG-47 to UG-50
Design of closure member of jacket to vessel	4.11.3.1	Part 5	UG-101
Design of partial jackets	4.11.5.2(b)	Part 5	UG-101(p)

GENERAL NOTE: As an example, when applying 4.11.2.1 for loadings or design loads and load case combinations, substitute reference to 4.1 with reference to UG-22.

Table UJV-1-3
Figure Cross-Reference List

Division 1		
Figure Deleted in 2025	Formerly Referenced in	Division 2
9-2	Nonmandatory Appendix W, Table W-3, Ref. No. (33)	Figure 4.11.1
9-5	UW-3; Nonmandatory Appendix W, Table W-3, Ref. No. (34)	Table 4.11.1
9-7	ULW-22(a)	Figure 4.11.2

GENERAL NOTE: As an example, in the 2023 Edition, Figure 9-2 was referenced in Nonmandatory Appendix W, Table W-3. Table W-3 now references Section VIII, Division 2, Figure 4.11.1 since Figure 9-2 has been deleted.

PART UNC
VESSELS OF NONCIRCULAR CROSS SECTION

(25)

UNC-1 GENERAL

(a) The rules in this Part cover minimum requirements for the design, fabrication, and inspection of single-wall vessels having a rectangular or obround cross section. The rules of this Part apply to the walls and parts of the vessels subject to pressure stresses including stiffening, reinforcing, and staying members.

(1) Design requirements for noncircular vessels in Section VIII, Division 2, 4.12 shall be used in lieu of those previously listed in Mandatory Appendix 13. Table UNC-1-1 lists the new locations for all requirements formerly located in this Division.

(2) The Division 1 design requirements listed in Table UNC-1-2 shall be used in lieu of the corresponding design requirements referenced in Division 2, 4.12.

(3) When a Mandatory Appendix 13 paragraph, table, or figure is referenced, the applicable section of Division 2 shall be used in accordance with UG-16(a) and Mandatory Appendix 46, except as indicated in Table UNC-1-2.

(b) Requirements other than design shall be in accordance with this Part.

(c) The rules in this Part cover some common types of noncircular cross section vessels but are not intended to limit configurations to those described herein. Designs that differ from those covered in this Part shall be in accordance with paragraph U-2(g).

UNC-2 MATERIALS

Materials used in the fabrication of vessels described in this Part shall be in accordance with Subsection A.

UNC-3 FABRICATION

(a) Fabrication of vessels shall be in accordance with the applicable Parts of Subsection A and Subsection B, Part UW, except as otherwise provided for in this Part. Category A joints (see UW-3) may be of Type No. (3) of Table UW-12 when the thickness does not exceed $^5/_8$ in. (16 mm).

(b) This Part covers fabrication of vessels by welding. Other methods of fabrication are permissible, provided the requirements of applicable Parts of this Section are met.

UNC-4 INSPECTION

Inspection and testing shall be carried out as stated in Subsection A.

UNC-5 EXAMPLES

See UG-16(f).

Table UNC-1-1
Paragraph Cross-Reference List

2023 Division 1 Paragraph, Topic	Division 2
13-1, Scope	4.12.1
13-2, Types of vessels	4.12.1
13-4, Design of vessels of noncircular cross section	4.12.2
13-5, Nomenclature	4.12.11
13-6, Ligament efficiency of multidiameter holes in plates	4.12.6
13-7, Unreinforced vessels of rectangular cross section	Tables 4.12.2, 4.12.3, and 4.12.4
13-8, Reinforced vessels of rectangular cross section	4.12.3 and Tables 4.12.5, 4.12.6, and 4.12.7
13-9, Stayed vessels of rectangular cross section	4.12.4, 4.12.9, and Tables 4.12.8 and 4.12.9
13-10, Unreinforced vessels having an obround cross section	Table 4.12.10
13-11, Reinforced vessels of obround cross section	Table 4.12.11
13-12, Stayed vessels of obround cross section	Table 4.12.12
13-13, Vessels of circular cross section having a single diametrical staying member	4.12.4 and Table 4.12.13
13-14, Vessels of noncircular cross section subject to external pressure	4.12.8
13-18, Special calculations	4.12.5 and 4.12.6
Tables	4.12.12
Figures	4.12.13

Table UNC-1-2
Division 2 Cross-Reference List to Division 1 Requirements

Topic	Division 2		Division 1
	Paragraph	Reference	
Alternate design	4.12.1	Part 5	U-2(g)
Alternate design	4.12.2	Part 5	U-2(g)
Flat plates	4.12.2.6	4.6	UG-34
Nozzles	4.12.2.9	4.5.2	UG-36(c)(3)
Alternate design	4.12.3	Part 5	U-2(g)
Fabrication	4.12.3.2	Part 6	UG-79, UCS-79, and UHT-79
Stay plates and stay bolts	4.12.4.1	4.9	UG-47, UG-48, UG-49, and UG-50
Weld joint efficiency	4.12.6.1	4.2	UW-12
Ligaments	4.12.6.3	4.1	UG-53
Alternate design	4.12.9	Part 5	U-2(g)
Fabrication	4.12.10.1	Applicable Parts of this Division	Subsection A and Subsection B
Stay plates	4.12.11	Table 4.9.1	UG-47
Allowable stress	4.12.11	Annex 3-A	UG-23
Yield stress	4.12.11	Annex 3-D	UG-23(f)
Young's modulus (modulus of elasticity)	4.12.11	Annex 3-E	Section II, Part D, Tables TM-1, TM-2, TM-3, TM-4, and TM-5

GENERAL NOTE: As an example, when applying 4.12.1, substitute reference to Part 5 with reference to U-2(g).

PART UPX PLATE HEAT EXCHANGERS

(25)

UPX-1 SCOPE

The rules of this Part cover the minimum requirements for design, fabrication, assembly, inspection, testing, and documentation of gasketed, semiwelded, welded, and brazed plate heat exchangers (PHEs).

These rules cover the common types of PHEs and their elements but are not intended to limit the configurations or details to those illustrated or otherwise described herein. Designs that differ from those covered in this Part, as well as other types of PHEs, shall be in accordance with U-2(g).

UPX-2 MATERIALS OF CONSTRUCTION

All pressure-containing parts shall be constructed using materials permitted by this Division. Metallic and nonmetallic materials not permitted by this Division may be used specifically for heat transfer plates within the PHE, provided there is an applicable Code Case published for the limited use of this material as heat transfer plates within a plate pack.

UPX-3 TERMINOLOGY

UPX-3.1 GENERAL

brazed plate heat exchanger (PHE): an assembly consisting of fully brazed heat transfer plates. The heat transfer plates are stacked on top of each other and brazed together. The nozzles can be located on any fixed endplate.

fully welded plate heat exchanger (PHE): an assembly consisting of fully welded heat transfer plates and its supporting frame. The frame provides structural support and pressure containment and consists of two fixed endplates and, if applicable, frame compression bolts. The frame may be fully bolted, fully welded, or a combination of bolted and welded. The heat transfer plates are fully welded to form a plate pack, and one or more plate packs can be assembled in the frame. The nozzles or connections can be located on the top, bottom, front, side, or back endplates.

gasketed or semiwelded plate heat exchanger (PHE): an assembly of components consisting of gasketed or semiwelded heat transfer plates and its supporting frame. The gaskets provide periphery sealing between the compressed heat transfer plates or between the semiwelded plate pairs. The gaskets also provide additional sealing between adjacent heat transfer plates to prevent intermixing of the operating fluids. The frame provides structural support and pressure containment and consists of the fixed endplate, movable endplate, upper carrying bar, lower guide bar, support column, and frame compression bolts. The gasketed or semiwelded gasketed heat transfer plates are compressed between the fixed endplate and movable endplate by the frame compression bolts. The heat transfer plates and movable endplate are supported by the upper carrying bar and aligned with the lower guide bar. The support column provides structural support for the upper carrying bar and lower guide bar. The nozzles or connections can be located on the fixed endplate, movable endplate, or connection plate; see Figure UPX-3.1-1.

UPX-3.2 DEFINITIONS OF GASKETED OR SEMIWELDED PHE COMPONENTS

connection plate: an intermediary "endplate" located in the plate pack that permits additional nozzles, additional fluids, and redirection of flow patterns.

divider plate: a plate that changes the direction of the flow of the fluid in a two-pass or larger heat exchanger. Also called a turning plate.

fixed endplate: a fixed plate that provides pressure containment and locations for the nozzles or connections; it may or may not come with feet.

frame: a general term that describes structural support and pressure-containment components. The components may consist of a fixed endplate, a movable endplate, upper carrying and lower guide bars, a support column, and frame compression bolts.

frame compression bolt: a bolt assembly used to compress the fixed endplate, movable endplate, and heat transfer plates to affect a pressure seal.

gasket: a sealing element between single plates or semiwelded plate pairs.

heat transfer plate: a thin corrugated plate that makes up the plate pack and is in contact with the process fluids.

movable endplate: a movable plate that provides pressure containment and locations for the nozzles or connections.

plate pack: a collection of all gasketed or semiwelded heat transfer plates in the frame.

semiwelded plate pair: two adjacent heat transfer plates welded together. The weld replaces the gasket between the two adjacent plates. A gasket is required between each plate pair.

support column: the structural component that supports the upper carrying and lower guide bars of the frame.

lower guide bar: a structural component that aligns the heat transfer plates and movable endplate.

upper carrying bar: a structural component that supports the heat transfer plates, movable endplate, and internal fluids.

UPX-3.3 DEFINITIONS OF FULLY WELDED PHE COMPONENTS

endplate: a plate that provides pressure containment and location for nozzles and/or connections.

frame: a general term that describes structural support and pressure-containment components. The components may consist of top and bottom endplates, front and back endplates, side plates, and, if applicable, frame compression bolts.

frame compression bolts: bolts used to compress the top, bottom, front, back, and side plates to affect a pressure seal.

welded plate pack: a collection of heat transfer plates in which all plates are fully welded together. No gaskets are required between the plates of fully welded PHEs.

UPX-3.4 DEFINITIONS OF BRAZED PHE COMPONENTS

fixed endplate: a plate that provides pressure containment and attachment of locations for the nozzles.

plate pack: a collection of heat transfer plates in which all plates are furnace brazed together. No gaskets are required for a brazed PHE.

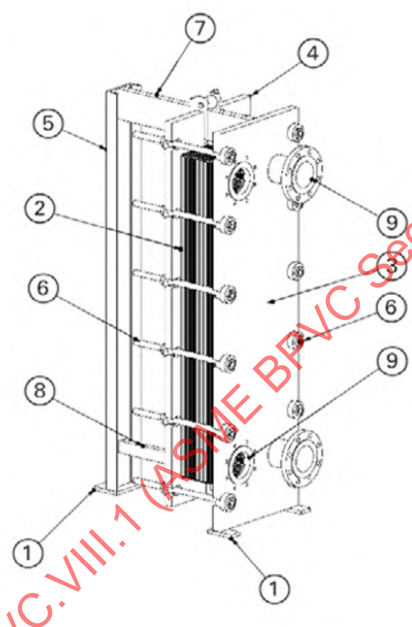
UPX-4 CONDITIONS OF APPLICABILITY

The design aspects covered in this Part apply to the metallic, pressure-retaining components that are considered in the calculation of the MAWP. Metallic or nonmetallic liners used to avoid contact of the process fluid with the components are not addressed in this Part.

UPX-5 DESIGN CONSIDERATIONS

(a) Plate Packs Using Gaskets. Gasketed plate packs shall be designed to contain pressurized fluid without leaking to a pressure of at least 1.3 times the MAWP.

Figure UPX-3.1-1
Typical Plate Heat Exchanger



Legend:
1 = feet (optional)
2 = heat transfer plates
3 = fixed endplate
4 = movable endplate
5 = support column
6 = frame compression bolts
7 = upper carrying bar
8 = lower guide bar
9 = connections

The MAWP of gasketed plate packs may be determined without performing proof testing or design calculations for the gasketed plate pack, provided the following requirements are met:

(1) The MAWP for the plate heat exchanger shall be determined considering all other pressure-retaining parts, including the endplates, bolting, and nozzles.

(2) The nominal thickness of a single-wall heat transfer plate or the combined thickness of a double-wall heat transfer plate shall not be less than 0.014 in. (0.35 mm).

(3) The heat exchanger shall not be used in lethal service [see UW-2(a)].

(b) Fully Welded PHEs. The MAWP of fully welded PHEs may be determined using methods found in UG-101.

(c) Brazed PHEs. The MAWP of brazed PHEs may be determined using methods found in UG-101.

(d) All Other PHE Components. Components of PHEs that have applicable rules within this Division shall be designed in accordance with these rules.

UPX-6 CALCULATION PROCEDURE

(a) Nomenclature

A_{PL} = wetted surface area
C_{PL} = total noncircular-shaped gasket length
d_{op} = finished diameter of circular opening (see Figure UPX-6-1)
D_{PL} = long span gasket centerline distance (see Figure UPX-6-1)
d_{PL} = short span gasket centerline distance (see Figure UPX-6-1)
D_r = long span frame compression bolt distance for openings reinforcement calculation (see Figure UPX-6-1)
d_r = short span frame compression bolt distance for openings reinforcement calculation (see Figure UPX-6-1)
$W_{m1,PL}$ = minimum required bolt load for the operating conditions
$W_{m2,PL}$ = minimum required bolt load for the gasket seating condition

Variables P, b, m, and y used in (b)(1), eq. (1) and (b)(2), eq. (4) are defined in Mandatory Appendix 2.

(b) Frame Compression Bolts. The frame compression bolt pattern is not required to be uniform. The frame compression bolt loads shall be determined using the methodology described in 2-5 except that (b)(1), eq. (1) and (b)(2), eq. (4) shall be used in lieu of 2-5(c)(1), eq. (1) and 2-5(c)(2), eq. (2).

(1) The required bolt load for the operating conditions, $W_{m1,PL}$, shall be determined in accordance with eq. (1) for plate heat exchanger with non-circular-shaped gaskets.

$$W_{m1,PL} = A_{PL}P + 2bC_{PL}mP \tag{1}$$

where A_{PL} and C_{PL} shall be either actual values for the design determined by the Manufacturer or calculated as follows:

$$A_{PL} = d_{PL}D_{PL} \tag{2}$$

$$C_{PL} = 2\left(d_{PL} + D_{PL}\right) \tag{3}$$

(2) The minimum initial bolt load required for non-circular-shaped gasket seating condition, $W_{m2,PL}$, shall be determined in accordance with eq. (4).

$$W_{m2,PL} = bC_{PL}y \tag{4}$$

(c) Fixed and Movable Endplates.

(1) Fixed and movable endplate calculations shall be performed in accordance with UG-34.

(2) Alternative calculations to those in (1) are permitted provided they are performed in accordance with Mandatory Appendix 46.

(d) Nozzle Reinforcement.

(1) When design calculations of endplates are performed in accordance with (c)(1), nozzle reinforcement calculations shall be performed in accordance with UG-39 except that the required endplate thickness used in the reinforcement calculations may be calculated in accordance with UG-34 using partial endplate short span d_r and large span D_r as shown in Figure UPX-6-1. All openings, including their limits of reinforcement, shall be within the rectangular area that has sides equal to short span d_r and large span D_r.

(2) When design calculations of endplates are performed in accordance with (c)(2), nozzle reinforcement calculations shall be performed in accordance with (c)(2).

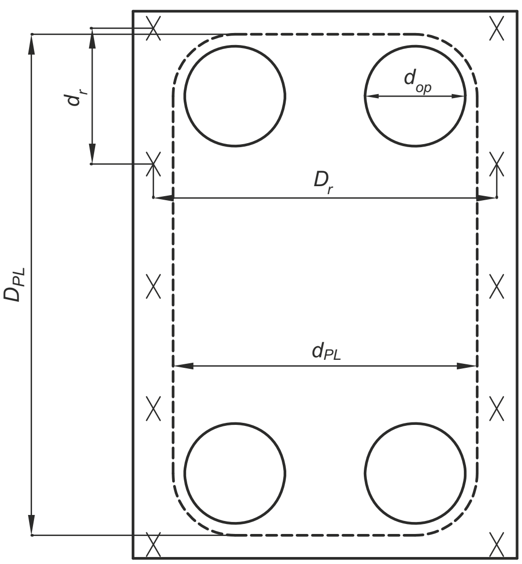
(e) Welded Connections. Welded nozzle connections shall meet the requirements of UW-15 and UW-16.

(f) Studded Connections. Studded connections shall meet the requirements of UG-43. The drilled holes may extend through the thickness of the endplate when there is no direct pressure or contact from the media at the location of the stud holes on the endplate.

UPX-7 PRESSURE TEST REQUIREMENTS

A PHE shall be hydrostatically tested in accordance with UG-99, or pneumatically tested in accordance with UG-100. The heat transfer plates shall not be included when determining the lowest stress ratio.

Figure UPX-6-1
PHE Dimensions



GENERAL NOTE: X denotes compression bolt location.

UPX-8 MANUFACTURER'S DATA REPORTS

A Manufacturer's Data Report (see Nonmandatory Appendix W, Form U-1P or Form U-3P) shall be completed by the Manufacturer for each PHE, or same-day production of identical vessels in accordance with Mandatory Appendix 35.

MANDATORY APPENDIX 1
SUPPLEMENTARY DESIGN FORMULAS

1-1 THICKNESS OF CYLINDRICAL AND SPHERICAL SHELLS

The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in UG-27(c) and UG-27(d):

(a) For cylindrical shells (circumferential stress),

$$t = \frac{PR_o}{SE + 0.4P} \quad \text{or} \quad P = \frac{SEt}{R_o - 0.4t} \qquad (1)$$

where

R_o = outside radius of the shell course under consideration

(b) For spherical shells,

$$t = \frac{PR_o}{2SE + 0.8P} \quad \text{or} \quad P = \frac{2SEt}{R_o - 0.8t} \qquad (2)$$

Other symbols are as defined in UG-27.

1-2 CYLINDRICAL SHELLS

(a) Circumferential Stress (Longitudinal Joints). When the thickness of the cylindrical shell under internal design pressure exceeds one-half of the inside radius, or when P exceeds $0.385SE$, the following equations shall apply. The following equations may be used in lieu of those given in UG-27(c):

When P is known and t is desired,

$$t = R\left(\exp\left[\frac{P}{SE}\right] - 1\right) = R_o\left(1 - \exp\left[\frac{-P}{SE}\right]\right) \qquad (1)$$

Where t is known and P is desired,

$$P = SE \log_e\left(\frac{R + t}{R}\right) = SE \log_e\left(\frac{R_o}{R_o - t}\right) \qquad (2)$$

(b) Longitudinal Stress (Circumferential Joints). When the thickness of the cylindrical shell under internal design pressure exceeds one-half of the inside radius, or when P exceeds $1.25SE$, the following equations shall apply:

When P is known and t is desired,

$$t = R\left(Z^{1/2} - 1\right) = R_o\left(\frac{Z^{1/2} - 1}{Z^{1/2}}\right) \qquad (3)$$

where

$$Z = \left(\frac{P}{SE} + 1\right)$$

When t is known and P is desired,

$$P = SE\left(Z - 1\right) \qquad (4)$$

where

$$Z = \left(\frac{R + t}{R}\right)^2 = \left(\frac{R_o}{R}\right)^2 = \left(\frac{R_o}{R_o - t}\right)^2$$

Symbols are as defined in UG-27 and 1-1.

1-3 SPHERICAL SHELLS

When the thickness of the shell of a wholly spherical vessel or of a hemispherical head under internal design pressure exceeds $0.356R$, or when P exceeds $0.665SE$, the following equations shall apply. The following equations may be used in lieu of those given in UG-27(d).

When P is known and t is desired,

$$t = R\left(\exp\left[\frac{0.50 \cdot P}{SE}\right] - 1\right) = R_o\left(1 - \exp\left[\frac{-0.50 \cdot P}{SE}\right]\right) \qquad (1)$$

When t is known and P is desired,

$$P = 2.0 \cdot SE \log_e\left(\frac{R + t}{R}\right) = 2.0 \cdot SE \log_e\left(\frac{R_o}{R_o - t}\right) \qquad (2)$$

Symbols are as defined in UG-27 and 1-1.

1-4 FORMULAS FOR THE DESIGN OF FORMED HEADS UNDER INTERNAL PRESSURE (25)

(a) The equations of this paragraph provide for the design of formed heads of proportions other than those given in UG-32, in terms of inside and outside diameter.

The equations in (c) and (d) given below shall be used for $t_s/L \geq 0.002$. For $t_s/L < 0.002$, the rules of (f) shall also be met.

(b) The symbols defined below are used in the equations of this paragraph (see Figure 1-4):

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a cone head at the point under consideration measured perpendicular to the longitudinal axis

D_o = outside diameter of the head skirt; or outside length of the major axis of an ellipsoidal head; or outside diameter of a cone head at the point under consideration measured perpendicular to the longitudinal axis

$D/2h$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head, and is used in Table 1-4.1

E = lowest efficiency of any Category A joint in the head (for hemispherical heads this includes head-to-shell joint). For welded vessels, use the efficiency specified in UW-12

E_T = modulus of elasticity at maximum design temperature, psi. The value of E_T shall be taken from the applicable Section II, Part D, Subpart 2, Table TM

h = one-half of the length of the minor axis of the ellipsoidal head, or the inside depth of the ellipsoidal head measured from the tangent line (head-bend line)

K = a factor in the equations for ellipsoidal heads depending on the head proportion $D/2h$

L = inside spherical or crown radius for torispherical and hemispherical heads

= K_1D for ellipsoidal heads in which K_1 is obtained from Table UG-37

L_o = outside spherical or crown radius

L/r = ratio of the inside crown radius to the inside knuckle radius, used in Table 1-4.2

M = a factor in the equations for torispherical heads depending on the head proportion L/r

P = internal design pressure (see UG-21)

r = inside knuckle radius

S = maximum allowable working stress, as given in Subsections C and D except as limited by endnote[64], UG-24, UG-32(d), and UW-12

S_y = yield strength from UG-23(f) at maximum design temperature

t = minimum required thickness of head after forming

t_s = minimum specified thickness of head after forming, in. (mm). t_s shall be $\geq t$

α = one-half of the included (apex) angle of the cone at the centerline of the head

(c) Ellipsoidal Heads [64]

$$t = \frac{PDK}{2SE - 0.2P} \text{ or } P = \frac{2SEt}{KD + 0.2t} \quad (1)$$

$$t = \frac{PD_oK}{2SE + 2P(K - 0.1)}$$

or

$$P = \frac{2SEt}{KD_o - 2t(K - 0.1)} \quad (2)$$

where

$$K = \frac{1}{6}\left[2 + \left(\frac{D}{2h}\right)^2\right]$$

Numerical values of the factor K are given in Table 1-4.1.

(d) Torispherical Heads[64]

$$t = \frac{PLM}{2SE - 0.2P} \text{ or } P = \frac{2SEt}{LM + 0.2t} \quad (3)$$

$$t = \frac{PL_oM}{2SE + P(M - 0.2)}$$

or

$$P = \frac{2SEt}{ML_o - t(M - 0.2)} \quad (4)$$

where

$$M = \frac{1}{4}\left(3 + \sqrt{\frac{L}{r}}\right)$$

Numerical values of the factor M are given in Table 1-4.2.

(e) Conical Heads

$$t = \frac{PD}{2 \cos\alpha\left(SE - 0.6P\right)}$$

or

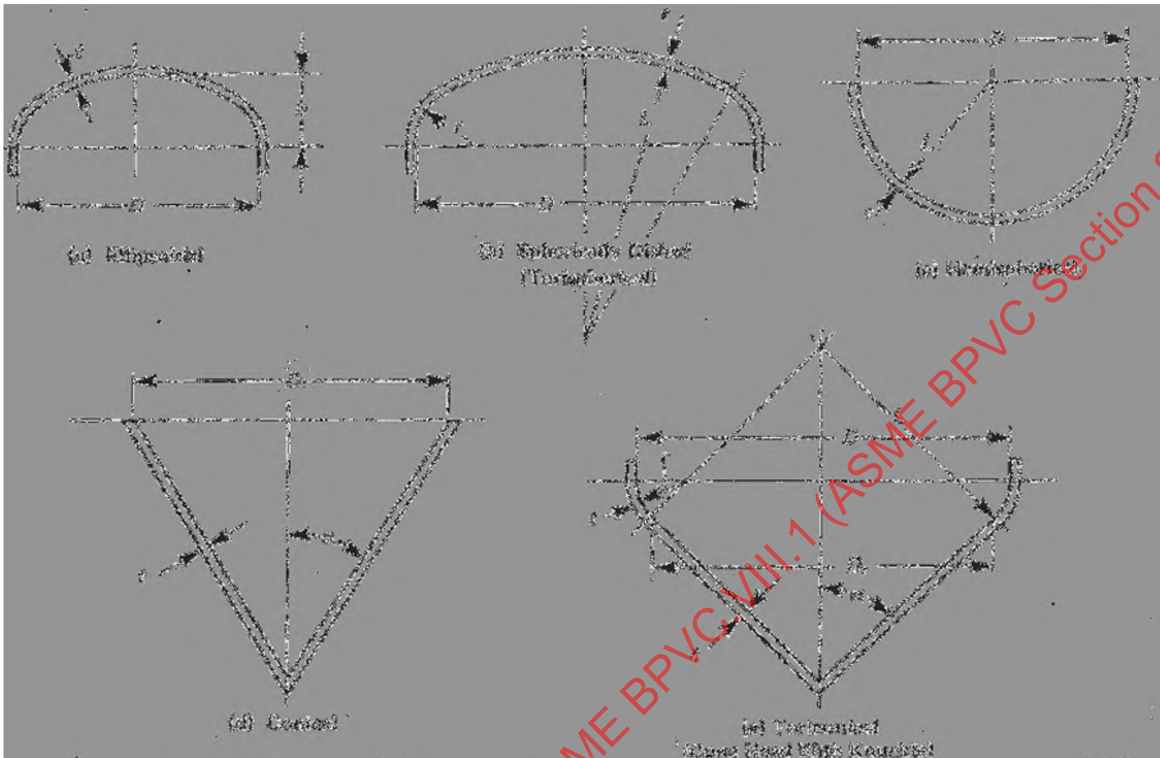
$$P = \frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha} \quad (5)$$

$$t = \frac{PD_o}{2\cos\alpha\left(SE + 0.4P\right)}$$

or

$$P = \frac{2SEt\cos\alpha}{D_o - 0.8t\cos\alpha} \quad (6)$$

Figure 1-4
Principal Dimensions of Typical Heads



(f) Design of Heads With $t_s/L < 0.002$. The following rules shall be used when the maximum design temperature is less than or equal to the temperature limit given in Table 1-4.3. See U-2(g) for maximum design temperature exceeding the temperature limit given in Table 1-4.3

(1) Torispherical Heads With $t_s/L < 0.002$. The minimum required thickness of a torispherical head having $0.0005 \le t_s/L < 0.002$ shall be the larger of the thicknesses calculated by the equations in UG-32(d) or in (d) above, and by the equations given below.

(-a) Calculate a coefficient, C_1.

$$C_1 = 9.31\,r/D - 0.086, \text{ for } r/D \le 0.08$$
$$C_1 = 0.692\,r/D + 0.605, \text{ for } r/D > 0.08$$

(-b) Calculate the elastic buckling stress, S_e.

$$S_e = C_1 E_T (t_s/r)$$

(-c) Calculate a coefficient, C_2.

$$C_2 = 1.25, \text{ for } r/D \le 0.08$$
$$C_2 = 1.46 - 2.6\,r/D, \text{ for } r/D > 0.08$$

Table 1-4.1
Values of Factor *K*

D*/2*h	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
D*/2*h	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	...
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	...

GENERAL NOTE: Use nearest value of $D/2h$; interpolation unnecessary.

Table 1-4.2
Values of Factor *M*

L/r	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
L/r	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
L/r	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	$16^2/_3$ [Note (1)]
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77

GENERAL NOTE: Use nearest value of L/r; interpolation unnecessary.

NOTE:
(1) Maximum ratio allowed by UG-32(i) when L equals the outside diameter of the skirt of the head.

(-d) Calculate values of constants a, b, β, and ϕ.

$$a = 0.5D - r$$
$$b = L - r$$
$$\beta = \arccos(a/b), \text{radians}$$
$$\phi = \left(\sqrt{Lt_s}\right)/r, \text{radians}$$

(-e) Calculate the value of c.

If ϕ is less than β, then

$$c = a\left[\cos(\beta - \phi)\right]$$

If ϕ is equal to or greater than β, then

$$c = a$$

Determine the value of R_e.

$$R_e = c + r$$

(-f) Calculate the value of internal pressure expected to produce elastic buckling, P_e.

$$P_e = \frac{S_e t_s}{C_2 R_e\left[\left(0.5R_e / r\right) - 1\right]}$$

(-g) Calculate the value of internal pressure expected to result in yield stress at the point of maximum stress, P_y.

$$P_y = \frac{S_y t_s}{C_2 R_e\left[\left(0.5R_e / r\right) - 1\right]}$$

(-h) Calculate the value of internal pressure expected to result in knuckle failure, P_{ck}.

$$P_{ck} = 0.6P_e, \text{for } P_e / P_y \le 1.0$$
$$P_{ck} = 0.408P_y + 0.192P_e, \text{for } 1.0 < P_e / P_y \le 8.29$$
$$P_{ck} = 2.0P_y, \text{for } P_e / P_y > 8.29$$

(-i) Calculate the value $P_{ck}/1.5$. If $P_{ck}/1.5$ is equal to or greater than the required internal design pressure P, then the design is complete. If $P_{ck}/1.5$ is less than the required internal design pressure P, then increase the thickness and repeat the calculations.

(2) Design of Ellipsoidal Heads With $t_s/L < 0.002$. The minimum required thickness of an ellipsoidal head having $0.0005 \le t_s/L < 0.002$ shall be the larger of the thicknesses calculated by the equations in UG-32(c) or in (c) above, and (1). In using the equations in (1), the value of L is to be obtained from Table UG-37 and the value of r is to be obtained from Table 1-4.4.

Table 1-4.3
Maximum Metal Temperature

Table in Which Material Is Listed	Temperature, °F
Table UCS-23	700
Table UNF-23.1	300
Table UNF-23.2	150
Table UNF-23.3	900
Table UNF-23.4	600
Table UNF-23.5	600
Table UHA-23	800
Table UHT-23	700

1-5 RULES FOR CONICAL REDUCER SECTIONS AND CONICAL HEADS UNDER INTERNAL PRESSURE (25)

(a) The equations of (d) and (e) below provide for the design of reinforcement, if needed, at the large and small ends for conical reducer sections and conical heads where

Table 1-4.4
Values of Knuckle Radius, r

$D/2h$	r/D
3.0	0.10
2.8	0.11
2.6	0.12
2.4	0.13
2.2	0.15
2.0	0.17
1.8	0.20
1.6	0.24
1.4	0.29
1.2	0.37
1.0	0.50

GENERAL NOTE: Interpolation permitted for intermediate values.

all the elements have a common axis and the half-apex angle $\alpha \le 30$ deg. Subparagraph (g) below provides for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where α is greater than 30 deg.

In the design of reinforcement at the large and small ends of cones and conical reducers, the requirements of UG-41 shall be met.

(b) Nomenclature

A_{eL} = effective area of reinforcement at large end intersection
A_{es} = effective area of reinforcement at small end intersection
A_{rL} = required area of reinforcement at large end of cone
A_{rs} = required area of reinforcement at small end of cone
E_1 = efficiency of longitudinal joint in cylinder. For compression (such as at large end of cone), E_1 = 1.0 for butt welds.
E_2 = efficiency of longitudinal joint in cone. For compression, E_2 = 1.0 for butt welds.
E_c = modulus of elasticity of cone material
E_r = modulus of elasticity of reinforcing ring material
E_s = modulus of elasticity of cylinder material
f_1 = axial load per unit circumference at large end due to wind, dead load, etc., excluding pressure
f_2 = axial load per unit circumference at small end due to wind, dead load, etc., excluding pressure
P = internal design pressure (see UG-21)
Q_L = algebraical sum of $PR_L/2$ and f_1
Q_s = algebraical sum of $PR_s/2$ and f_2
R_L = inside radius of large cylinder at large end of cone
R_s = inside radius of small cylinder at small end of cone
S_c = allowable stress of cone material at design temperature
S_r = allowable stress of reinforcing ring material at design temperature
S_s = allowable stress of cylinder material at design temperature
t = minimum required thickness of cylinder at cone-to-cylinder junction
t_c = nominal thickness of cone at cone-to-cylinder junction
t_r = minimum required thickness of cone at cone-to-cylinder junction
t_s = nominal thickness of cylinder at cone-to-cylinder junction
y = cone-to-cylinder factor
= S_sE_s for reinforcing ring on shell
= S_cE_c for reinforcing ring on cone
Δ = angle indicating need for reinforcement at cone-to-cylinder junction having a half-apex angle $\alpha \le 30$ deg. When $\Delta \ge \alpha$, no reinforcement is required at the junction, deg.
α = half-apex angle of cone or conical section, deg.

(c) For conical reducers and conical heads, the following values shall be determined at large end and again at the small end in order that both the large end and the small end can be examined:

(1) When a cylinder having a minimum length of $2.0\sqrt{R_L t_s}$ is attached to the large end of the cone, determine P/S_sE_1 and then determine Δ at the large end from (d)(1), eq. (1).

(2) When a cylinder having a minimum length of $1.4\sqrt{R_s t_s}$ is attached to the small end of the cone, determine P/S_sE_1 and then determine Δ at the small end from (e)(1), eq. (6).

(3) Determine k:

k = 1 when additional area of reinforcement is not required
= y/S_rE_r when a stiffening ring is required, but k is not less than 1.0

(d) Reinforcement shall be provided at the large end of the cone when required by the following:

(1) For cones attached to a cylinder having a minimum length of $2.0\sqrt{R_L t_s}$, reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ obtained from eq. (1), using the appropriate ratio P/S_sE_1, is less than α.

$$\Delta = 326.6\sqrt{P/S_sE_1} \tag{1}$$

The required area of reinforcement shall be at least equal to that indicated by the following formula when Q_L is in tension:

$$A_{rL} = \frac{kQ_L R_L}{S_s E_1}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha \qquad (2)$$

At the large end of the cone-to-cylinder juncture, the $PR_L/2$ term is in tension. When f_1 is in compression and the quantity is larger than the $PR_L/2$ term, the design shall be in accordance with U-2(g). The calculated localized stresses at the discontinuity shall not exceed the stress values specified in (g)(1) and (g)(2).

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eL} = \left(t_s - t\right)\sqrt{R_L t_s} + \left(t_c - t_r\right)\sqrt{R_L t_c/\cos\alpha} \qquad (3)$$

Any additional area of reinforcement that is required shall be situated within a distance of $\sqrt{R_L t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.25 \times \sqrt{R_L t_s}$ from the junction.

(2) For cones attached to flat covers, flanges, or other components where the length of cylinder, if present, is less than $2.0\sqrt{R_L t_s}$, the required reinforcement shall be at least equal to that indicated by the following formula:

$$A_{rL} = \frac{kQ_L R_L}{S_c E_2}\tan\alpha \qquad (4)$$

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eL} = \left(t_c - t_r\right)\sqrt{R_L t_c/\cos\alpha} \qquad (5)$$

Any additional area of reinforcement that is required shall be added to the cone.

(e) Reinforcement shall be provided at the small end of the cone when required by the following:

(1) For cones attached to a cylinder having a minimum length of $1.4\sqrt{R_s t_s}$, reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of Δ obtained from eq. (6), using the appropriate ratio $P/S_s E_1$, is less than α.

$$\Delta = 89\sqrt{P/S_s E_1} \qquad (6)$$

The required area of reinforcement shall be at least equal to that indicated by the following formula when Q_s is in tension:

$$A_{rs} = \frac{kQ_s R_s}{S_s E_1}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha \qquad (7)$$

At the small end of the cone-to-cylinder juncture, the $PR_s/2$ term is in tension. When f_2 is in compression and the quantity is larger than the $PR_s/2$ term, the design shall be in accordance with U-2(g). The calculated localized stresses at the discontinuity shall not exceed the stress values specified in (g)(1) and (g)(2).

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{es} = 0.78\left[\sqrt{R_s t_s}\left(t_s - t\right) + \sqrt{\left(R_s t_c/\cos[\alpha]\right)}\left(t_c - t_r\right)\right] \qquad (8)$$

Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.25\sqrt{R_s t_s}$ from the junction.

(2) For cones attached to flat covers, flanges, or other components where the length of cylinder, if present, is less than $1.4\sqrt{R_s t_s}$, the required reinforcement shall be at least equal to that indicated by the following formula:

$$A_{rS} = \frac{kQ_s R_s}{S_c E_2}\tan\alpha \qquad (9)$$

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eS} = 0.78\sqrt{\left(R_s t_c/\cos[\alpha]\right)}\left(t_c - t_r\right) \qquad (10)$$

Any additional area of reinforcement that is required shall be added to the cone.

(f) Reducers not described in UG-36(e)(5), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (g).

(g) When the half-apex angle α is greater than 30 deg (0.52 rad), cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on special analysis, such as the beam-on-elastic-foundation analysis of Timoshenko, Hetenyi, or Watts and Lang. See U-2(g). When such an analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values:

(1) Membrane hoop stress plus average discontinuity hoop stress shall not be greater than $1.5S$, where the "average discontinuity hoop stress" is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson's ratio times the longitudinal stress at the surfaces.

(2) Membrane longitudinal stress plus discontinuity longitudinal stress due to bending shall not be greater than S_{PS} [see UG-23(e)].

The angle joint (see Mandatory Appendix 3, 3-2) between the cone and cylinder shall be designed equivalent to a double butt-welded joint, and because of the high bending stress, there shall be no weak zones around the angle joint. The thickness of the cylinder may have to be increased to limit the difference in thickness so that the angle joint has a smooth contour.

(25) 1-6 DISHED COVERS (BOLTED HEADS)

(a) Dished heads with bolting flanges, both concave and convex to the pressure and conforming to the several types illustrated in Figure 1-6, shall be designed in accordance with the equations which follow. Flanges designed to Figure 1-6, sketches (b), (c), and (d) do not need to comply with the rules in 2-14.

(b) The symbols used in the equations of this paragraph are defined as follows:

A = outside diameter of flange
B = inside diameter of flange
C = bolt circle, diameter
L = inside spherical or crown radius
M_o = the total moment determined as in Mandatory Appendix 2 for the operating condition and the gasket seating condition except that for heads of the type shown in Figure 1-6, sketch (d), H_D and h_D shall be as defined below, and an additional moment $H_r h_r$ (which may add or subtract) shall be included where

H_D = axial component of the membrane load in the spherical segment acting at the inside of the flange ring
= $0.785\ B^2 P$
h_D = radial distance from the bolt circle to the inside of the flange ring
H_r = radial component of the membrane load in the spherical segment acting at the intersection of the inside of the flange ring with the centerline of the dished cover thickness
= $H_D \cot \beta_1$
h_r = lever arm of force H_r about centroid of flange ring
β_1 = angle formed by the tangent to the centerline of the dished cover thickness at its point of intersection with the flange ring, and a line perpendicular to the axis of the dished cover
= $\arcsin \left(\frac{B}{2L + t} \right)$

NOTE: Since $H_r h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for flange design.

P = internal pressure (see UG-21) for the pressure on concave side, and external pressure for the pressure on convex side [see UG-28(f)]
r = inside knuckle radius
S = maximum allowable stress value (see UG-23)
T = flange thickness
t = minimum required thickness of head plate after forming

(c) It is important to note that the actual value of the total moment M_o may calculate to be either plus or minus for both the heads concave to pressure and the heads convex to pressure. However, for use in all of the equations that follow, the absolute values for both P and M_o are used.

(d) Heads of the type shown in Figure 1-6, sketch (a):

(1) the thickness of the head t shall be determined by the appropriate formula in UG-32 for pressure on concave side, and UG-33 for pressure on convex side; the thickness of the skirt shall be determined by the formula for cylindrical shell in UG-27 for pressure on concave side and UG-28 for pressure on convex side;

(2) the head radius L or the knuckle radius r shall comply with the limitations given in UG-32;

(3) the flange shall comply at least with the requirements of Mandatory Appendix 2, Figure 2-4 and shall be designed in accordance with the provisions of Mandatory Appendix 2 for pressure on concave and convex sides. When a slip-on flange conforming to the standards listed in Table U-3 is used, design calculations per Mandatory Appendix 2 need not be done provided the design pressure–temperature is within the pressure-temperature rating permitted in the flange standard.

(e) Heads of the type shown in Figure 1-6, sketch (b) (no joint efficiency factor is required):

(1) head thickness

(-a) for pressure on concave side,

$$t = \frac{5PL}{6S} \tag{1}$$

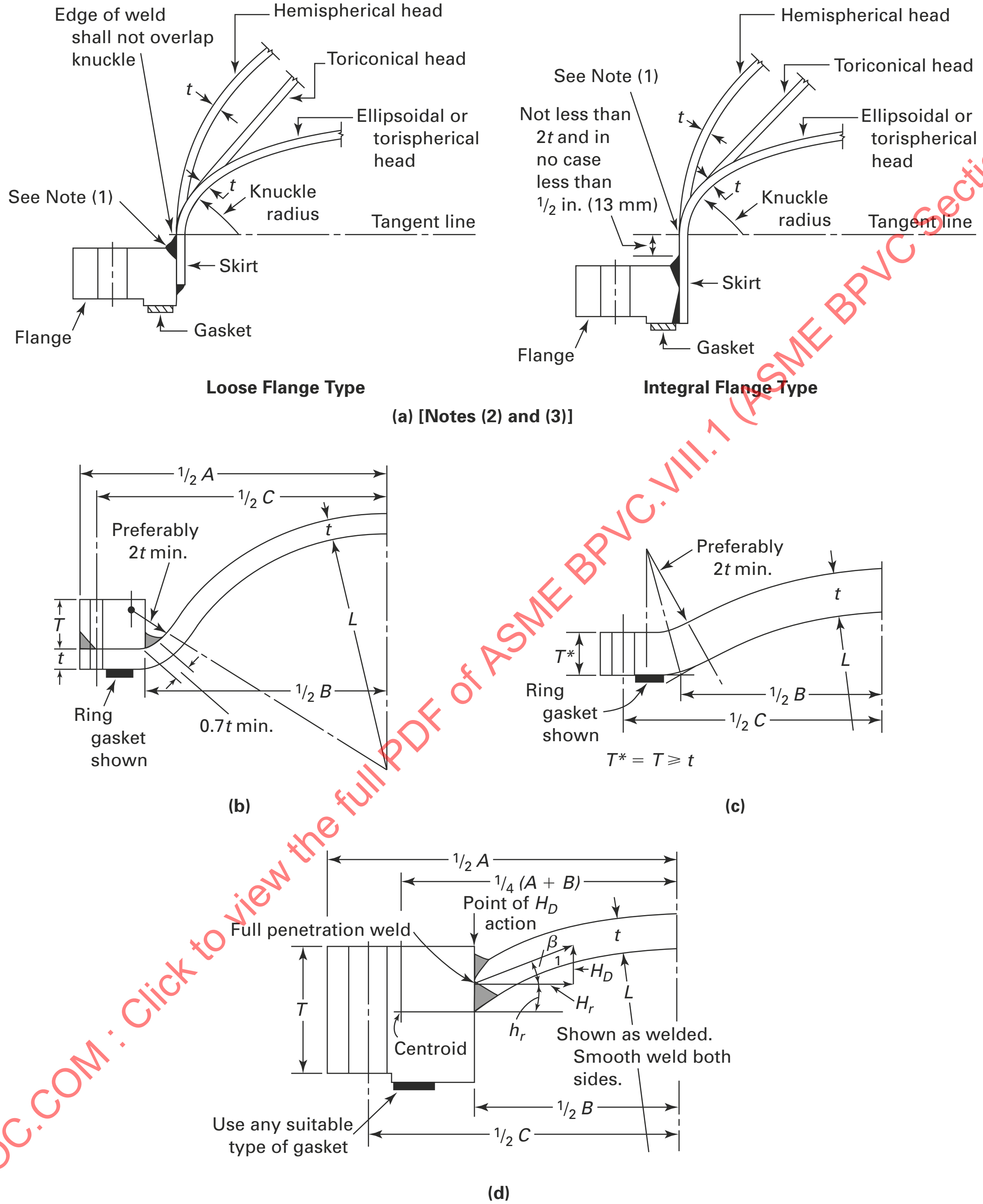
(-b) for pressure on convex side, the head thickness shall be determined based on UG-33(c) using the outside radius of the spherical head segment;

(2) flange thickness for ring gasket

$$T = \sqrt{\frac{M_o}{SB}\left[\frac{A+B}{A-B}\right]} \tag{2}$$

(3) flange thickness for full face gasket

Figure 1-6
Dished Covers With Bolting Flanges



NOTES:

(1) For head and skirt of different thicknesses, see Figure UW-13.1 for transition requirement.

(2) Welding details as shown are for illustrating the distance between the toe of the fillet weld and the tangent line of the head. Welding details shall be per Mandatory Appendix 2, Figure 2-4.

(3) An optional flange can be designed as loose type or integral type. When an optional flange is attached to a formed head per this sketch, the distance between the toe of the fillet weld and the tangent line of the head shall be as shown.

$$T = 0.6\sqrt{\frac{P}{S}\left[\frac{B(A+B)(C-B)}{A-B}\right]} \qquad (3)$$

NOTE: The radial components of the membrane load in the spherical segment are assumed to be resisted by its flange.

(f) Heads of the type shown in Figure 1-6, sketch (c) (no joint efficiency factor is required):

(1) head thickness

(-a) for pressure on concave side,

$$t = \frac{5PL}{6S} \qquad (4)$$

(-b) for pressure on convex side, the head thickness shall be determined based on UG-33(c) using the outside radius of the spherical head segment;

(2) flange thickness for ring gasket for heads with round bolting holes

$$T = Q + \sqrt{\frac{1.875M_o(C+B)}{SB(7C-5B)}} \qquad (5)$$

where

$$Q = \frac{PL}{4S}\left(\frac{C+B}{7C-5B}\right)$$

(3) flange thickness for ring gasket for heads with bolting holes slotted through the edge of the head

$$T = Q + \sqrt{\frac{1.875M_o(C+B)}{SB(3C-B)}} \qquad (6)$$

where

$$Q = \frac{PL}{4S}\left(\frac{C+B}{3C-B}\right)$$

(4) flange thickness for full-face gasket for heads with round bolting holes

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C-B)}{L}} \qquad (7)$$

where

$$Q = \frac{PL}{4S}\left(\frac{C+B}{7C-5B}\right)$$

(5) flange thickness for full-face gasket for heads with bolting holes slotted through the edge of the head

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C-B)}{L}} \qquad (8)$$

where

$$Q = \frac{PL}{4S}\left(\frac{C+B}{3C-B}\right)$$

(6) the required flange thickness shall be T as calculated in (2), (3), (4), or (5) above, but in no case less than the value of t calculated in (1) above.

(g) Heads of the type shown in Figure 1-6, sketch (d) (no joint efficiency factor is required):

(1) head thickness

(-a) for pressure on concave side,

$$t = \frac{5PL}{6S} \qquad (9)$$

(-b) for pressure on convex side, the head thickness shall be determined based on UG-33(c) using the outside radius of the spherical head segment;

(2) flange thickness

$$T = F + \sqrt{F^2 + J} \qquad (10)$$

where

$$F = \frac{PB\sqrt{4L^2 - B^2}}{8S(A-B)}$$

and

$$J = \left(\frac{M_o}{SB}\right)\left(\frac{A+B}{A-B}\right)$$

(h) These equations are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis which takes this into account may be used if it meets the requirements of U-2.

1-7 LARGE OPENINGS IN CYLINDRICAL AND CONICAL SHELLS

(a) Openings exceeding the dimensional limits given in UG-36(b)(1) shall be provided with reinforcement that complies with the following rules. Two-thirds of the required reinforcement shall be within the following limits:

(1) parallel to vessel wall: the larger of three-fourths times the limit in UG-40(b)(1), or equal to the limit in UG-40(b)(2);

(2) normal to vessel wall: the smaller of the limit in UG-40(c)(1), or in UG-40(c)(2).

(b) In addition to meeting the requirements of (a),

(1) for openings that are beyond the ratio specified in (-a), U-2(g) shall apply. Openings for radial nozzles that exceed the limits in UG-36(b)(1) and that also are within the range defined by all of the limits provided in (-a), (-b), and (-c) shall meet the requirements in (2), (3), and (4) below:

(-a) the ratio R_n/R does not exceed 0.7

(-b) vessel diameters greater than 60 in. (1 520 mm) I.D.;

(-c) nozzle diameters that exceed 40 in. (1 020 mm) I.D. and that also exceed $3.4\sqrt{Rt}$; the terms R and t are defined in Figures 1-7-1 and 1-7-2;

The rules are limited to radial nozzles in cylindrical and conical shells (with the half-apex angle equal to or less than 30 deg) that do not have internal projections, and do not include any analysis for stresses resulting from externally applied mechanical loads. For such cases, U-2(g) shall apply.

(2) The membrane stress S_m as calculated by eq. (4)(1) or (4)(2) below shall not exceed S, as defined in UG-37 for the applicable materials at design conditions. The maximum combined membrane stress S_m and bending stress S_b shall not exceed 1.5S at design conditions. S_b shall be calculated by eq. (4)(5) below.

(3) Evaluation of combined stresses from pressure and external loads shall be made in accordance with U-2(g).

(4) For membrane stress calculations, use the limits defined in Figure 1-7-1, and comply with the strength of reinforcement requirements of UG-41. For bending stress calculation, the greater of the limits defined in Figure 1-7-1 or Figure 1-7-2 may be used. The strength reduction ratio requirements of UG-41 need not be applied, provided that the allowable stress ratio of the material in the nozzle neck, nozzle forging, reinforcing plate, and/or nozzle flange divided by the shell material allowable stress is at least 0.80.

NOTE: The bending stress S_b calculated by eq. (5) is valid and applicable only at the nozzle neck-shell junction. It is a primary bending stress because it is a measure of the stiffness required to maintain equilibrium at the longitudinal axis junction of the nozzle-shell intersection due to the bending moment calculated by eq. (3).

Case A (see Figure 1-7-1)

$$S_m = P\left(\frac{R(R_n + t_n + \sqrt{R_m t}) + R_n(t + t_e + \sqrt{R_{nm} t_n})}{A_s}\right) \qquad (1)$$

Case B (see Figure 1-7-1)

$$S_m = P\left(\frac{R(R_n + t_n + \sqrt{R_m t}) + R_n(t + \sqrt{R_{nm} t_n})}{A_s}\right) \qquad (2)$$

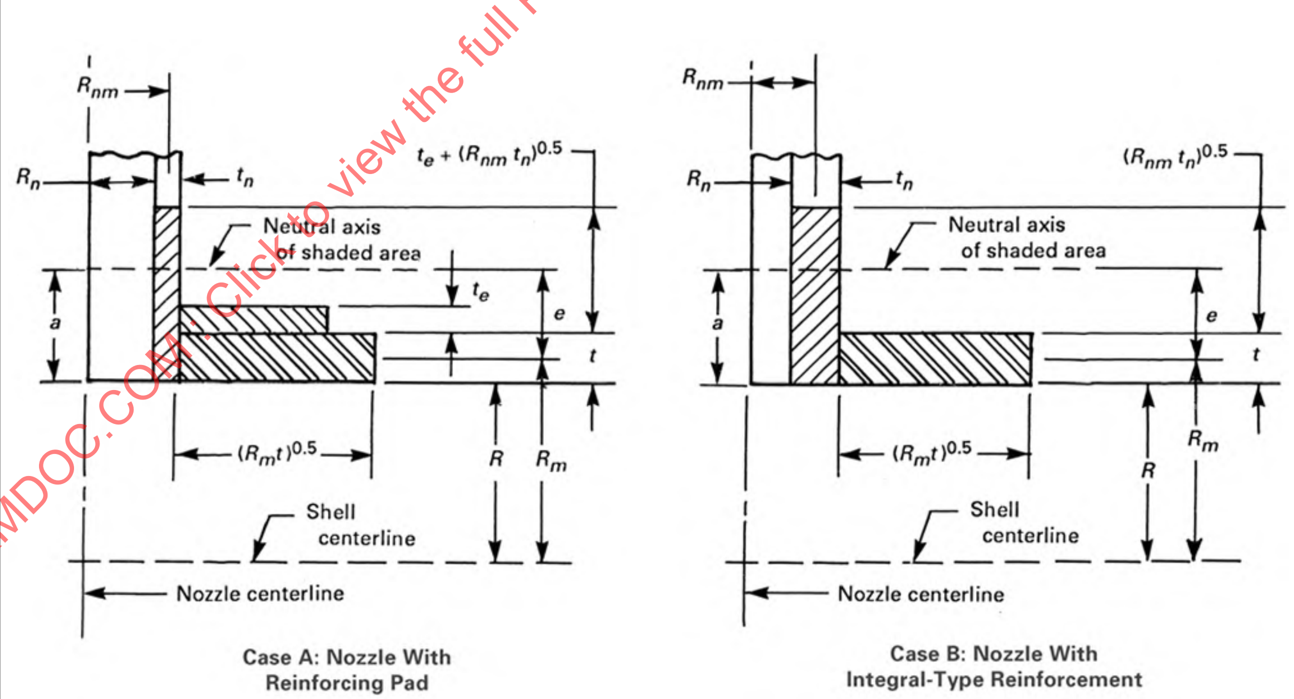
Cases A and B (See Figure 1-7-1 or Figure 1-7-2)

$$M = \left(\frac{R_n^3}{6} + R R_n e\right) P \qquad (3)$$

$$a = e + t/2 \qquad (4)$$

$$S_b = \frac{Ma}{I} \qquad (5)$$

Figure 1-7-1



(5) Nomenclature. Symbols used in Figures 1-7-1 and 1-7-2 are as defined in UG-37(a) and as follows:

A_s = shaded (cross-hatched) area in Figure 1-7-1, Case A or Case B
a = distance between neutral axis of the shaded area in Figure 1-7-1 or Figure 1-7-2 and the inside of vessel wall
e = distance between neutral axis of the shaded area and midwall of the shell
I = moment of inertia of the larger of the shaded areas in Figure 1-7-1 or Figure 1-7-2 about neutral axis
P = internal or external pressure
R_m = mean radius of shell
R_{nm} = mean radius of nozzle neck
S_b = bending stress at the intersection of inside of the nozzle neck and inside of the vessel shell along the vessel shell longitudinal axis
S_m = membrane stress calculated by eq. (4)(1) or eq. (4)(2)
S_y = yield strength from UG-23(f) for the material at test temperature

(c) In the design and fabrication of large openings, the Manufacturer should consider details that may be appropriate to minimize distortion and localized stresses around the opening. For example, reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening; weld may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations. The user and the Manufacturer should agree on the extent and type of nondestructive examination of welds that may be appropriate for the intended service conditions and the materials of construction. Proof testing may be appropriate in extreme cases of large openings approaching full vessel diameter, openings of unusual shape, etc.

(25) 1-8 RULES FOR REINFORCEMENT OF CONES AND CONICAL REDUCERS UNDER EXTERNAL PRESSURE

(a) The equations of (b) and (c) below provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half-apex angle α ≤ 60 deg. Subparagraph (e) below provides for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where α is greater than 60 deg.

In the design of reinforcement for a cone-to-cylinder juncture, the requirements of UG-41 shall be met.

The nomenclature given below is used in the equations of the following subparagraphs:

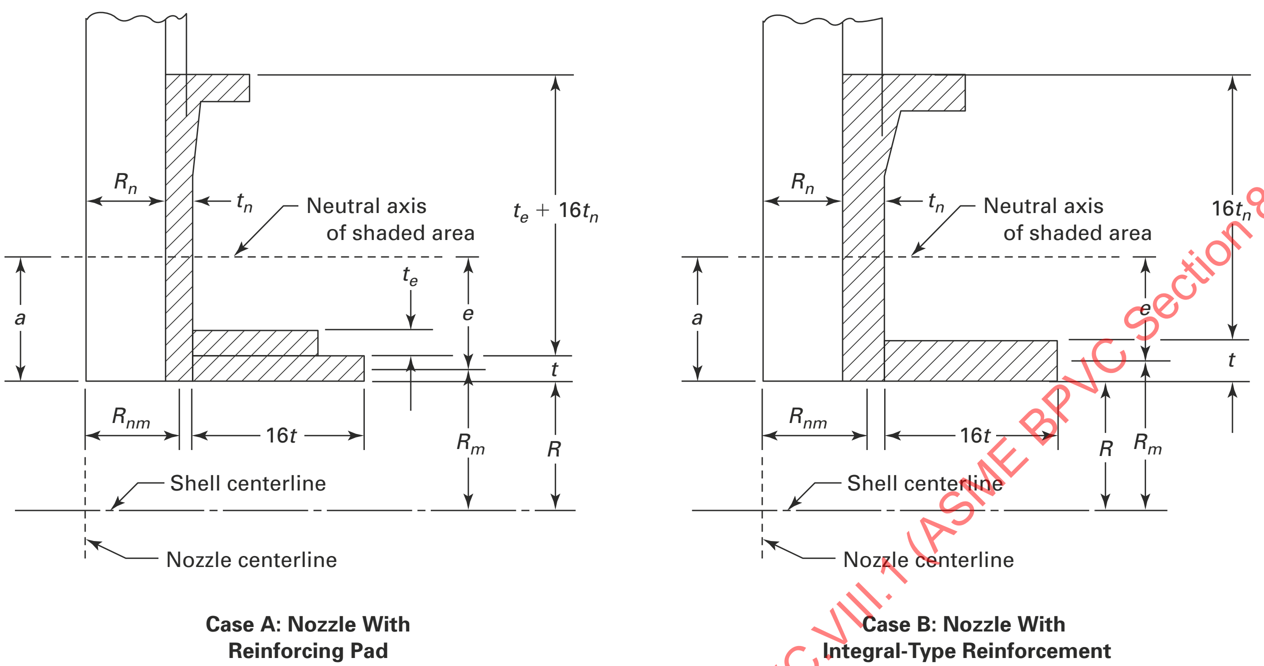
A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3
A_{eL} = effective area of reinforcement at large end intersection
A_{es} = effective area of reinforcement at small end intersection
A_{rL} = required area of reinforcement at large end of cone
A_{rs} = required area of reinforcement at small end of cone
A_s = cross-sectional area of the stiffening ring
A_T = equivalent area of cylinder, cone, and stiffening ring, where

$$A_{TL} = \frac{L_L t_s}{2} + \frac{L_c t_c}{2} + A_s \text{ for large end}$$

$$A_{TS} = \frac{L_s t_s}{2} + \frac{L_c t_c}{2} + A_s \text{ for small end}$$

B = factor determined from the applicable material chart in Section II, Part D, Subpart 3 for maximum design metal temperature [see UG-20(c)]
D_L = outside diameter of large end of conical section under consideration
D_o = outside diameter of cylindrical shell (In conical shell calculations, the value of D_s and D_L should be used in calculations in place of D_o depending on whether the small end D_s, or large end D_L, is being examined.)
D_s = outside diameter at small end of conical section under consideration
E_1 = efficiency of longitudinal joint in cylinder. For compression (such as at small end of cone), E_1 = 1.0 for butt welds.
E_2 = efficiency of longitudinal joint in cone. For compression, E_2 = 1.0 for butt welds.
E_c = modulus of elasticity of cone material
E_r = modulus of elasticity of stiffening ring material
E_s = modulus of elasticity of shell material
E_x = E_c, E_r, or E_s
f_1 = axial load per unit circumference at large end due to wind, dead load, etc., excluding pressure
f_2 = axial load per unit circumference at small end due to wind, dead load, etc., excluding pressure
I = available moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell
I' = available moment of inertia of combined shell-cone or ring-shell-cone cross section about its neutral axis parallel to the axis of the shell. The nominal shell thickness, t_s, shall be used, and the width of the shell which is taken as contributing to the moment of inertia of the combined section shall not be greater than $1.10\sqrt{Dt_s}$ and shall be taken

Figure 1-7-2



GENERAL NOTE: When any part of a flange is located within the greater of the $\sqrt{R_{nm}t_n} + t_e$ or $16t_n + t_e$ limit as indicated in Figure 1-7-1 or Figure 1-7-2 Case A, or the greater of $\sqrt{R_{nm}t_n}$ or $16t_n$ for Figure 1-7-1 or Figure 1-7-2 Case B, the flange may be included as part of the section that resists bending moment.

as lying one-half on each side of the cone-to-cylinder junction or of the centroid of the ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring.

CAUTION: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I'_s [see U-2(g)].

I_s = required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I'_s = required moment of inertia of the combined shell-cone or ring-shell-cone cross section about its neutral axis parallel to the axis of the shell

k = 1 when additional area of reinforcement is not required

= y/S_rE_r when a stiffening ring is required, but k is not less than 1.0

L = axial length of cone

L_c = length of cone between stiffening rings measured along surface of cone, in. (mm). For cones without intermediate stiffeners,

$$= \sqrt{L^2 + (R_L - R_s)^2}$$

L_L = design length of a vessel section taken as the largest of the following:

(a) the center-to-center distance between the cone-to-large-shell junction and an adjacent stiffening ring on the large shell;

(b) the distance between the cone-to-large-shell junction and one-third the depth of head on the other end of the large shell if no other stiffening rings are used.

L_s = design length of a vessel section taken as the largest of the following:

(a) the center-to-center distance between the cone-to-small-shell junction and adjacent stiffening ring on the small shell;

(b) the distance between the cone-to-small-shell junction and one-third the depth of head on the other end of the small shell if no other stiffening rings are used.

NOTE: If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

P = external design pressure

Q_L = algebraical sum of $PR_L/2$ and f_1

Q_s = algebraical sum of $PR_s/2$ and f_2

R_L = outside radius of large cylinder

R_s = outside radius of small cylinder

S_c = allowable stress of cone material at design temperature

S_r = allowable stress of stiffening ring material at design temperature

S_s = allowable stress of cylinder material at design temperature

t = minimum required thickness of cylinder at cone-to-cylinder junction [see UG-28(c)]

t_c = nominal thickness of cone at cone-to-cylinder junction

t_r = minimum required thickness of cone at cone-to-cylinder junction

t_s = nominal thickness of cylinder at cone-to-cylinder junction

y = cone-to-cylinder factor
= S_sE_s for stiffening ring on shell
= S_cE_c for stiffening ring on cone

α = one-half the included (apex) angle of the cone at the centerline of the head

Δ = value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \leq 60$ deg. When $\Delta \geq \alpha$, no reinforcement is required at the junction.

(b) Reinforcement shall be provided at the large end of the cone when required by (1) or (2). When the large end of the cone is considered a line of support, the moment of inertia for a stiffening ring shall be determined in accordance with (3).

(1) For cones attached to a cylinder having a minimum length of $2.0\sqrt{R_L t_s}$, reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ obtained from eq. (1) using the appropriate ratio P/S_sE_1 is less than α.

$$\Delta = 104\sqrt{P/S_sE_1} \tag{1}$$

The required area of reinforcement shall be at least equal to that indicated by the following formula when Q_L is in compression:

$$A_{rL} = \frac{kQ_LR_L\tan\alpha}{S_sE_1}\left[1 - \frac{1}{4}\left(\frac{PR_L - Q_L}{Q_L}\right)\frac{\Delta}{\alpha}\right] \tag{2}$$

At the large end of the cone-to-cylinder juncture, the $PR_L/2$ term is in compression. When f_1 is in tension and the quantity is larger than the $PR_L/2$ term, the design shall be in accordance with U-2(g). The calculated localized stresses at the discontinuity shall not exceed the stress values specified in 1-5(g)(1) and 1-5(g)(2).

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eL} = 0.55\left[\sqrt{D_Lt_s}\left(t_s - t\right) + \sqrt{\left(D_Lt_c/\cos[\alpha]\right)}\left(t_c - t_r\right)\right] \tag{3}$$

Any additional area of stiffening which is required shall be situated within a distance of $\sqrt{R_L t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.25 \times \sqrt{R_L t_s}$ from the junction.

(2) For cones attached to flat covers, flanges, or other components where the length of cylinder, if present, is less than $2.0\sqrt{R_L t_s}$, the required reinforcement shall be at least equal to that indicated by the following formula:

$$A_{rL} = \frac{kQ_LD_L}{2S_cE_2}\tan\alpha \tag{4}$$

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eL} = 0.55\sqrt{\left(D_Lt_c/\cos[\alpha]\right)}\left(t_c - t_r\right) \tag{5}$$

Any additional area of reinforcement that is required shall be added to the cone.

(3) When the cone-to-cylinder or knuckle-to-cylinder juncture is a line of support, the moment of inertia for a stiffening ring at the large end shall be determined by the procedure in Steps 1 through 8 below.

For cones attached to flat covers, flanges, or other components where the length of the cylinder, if present, is less than $2.0\sqrt{R_L t_s}$, length L_L in the formulas for A_{TL} and M shall be zero.

Step 1. Assuming that the shell has been designed and D_L, L_L, and t are known, select a member to be used for the stiffening ring and determine cross-sectional area A_{TL}. Then calculate factor B using the following formula. If F_L is a negative number, the design shall be in accordance with U-2(g):

$$B = \frac{3}{4}\left(\frac{F_LD_L}{A_{TL}}\right)$$

where

$$F_L = PM + f_1\tan\alpha$$

$$M = \frac{-R_L\tan\alpha}{2} + \frac{L_L}{2} + \frac{R_L^2 - R_s^2}{3R_L\tan\alpha}$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5 below.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For value of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E_x$. For value of B above the material/ temperature line for the design temperature, the design shall be either per U-2(g) or by changing the cone or cylinder configuration, stiffening ring location on the shell, and/or reducing the axial compressive force to reduce the B value to below or at the material/temperature line for the design temperature. For values of B having multiple values of A, such as when B falls on a horizontal portion of the curve, the smallest value of A shall be used.

Step 6. Compute the value of the required moment of inertia from the equations for I_s or I'_s. For the circumferential stiffening ring only,

$$I_s = \frac{AD_L{}^2A_{TL}}{14.0}$$

For the shell-cone or ring-shell-cone section,

$$I'_s = \frac{AD_L{}^2A_{TL}}{10.9}$$

Step 7. Determine the available moment of inertia of the ring only I or the shell-cone or ring-shell-cone I'.

Step 8. When the ring only is used,

$$I \geq I_s$$

and when the shell-cone or ring-shell-cone is used,

$$I' \geq I'_s$$

If the equation is not satisfied, a new section with a larger moment of inertia must be selected, and the calculation shall be done again until the equation is met.

The requirements of UG-29(b), UG-29(c), UG-29(d), UG-29(e), and UG-29(f) and UG-30 are to be met in attaching stiffening rings to the shell.

(c) Reinforcement shall be provided at the small end of the cone when required by (1) or (2). When the small end of the cone is considered a line of support, the moment of inertia for a stiffening ring shall be determined in accordance with (3).

(1) For cones attached to a cylinder having a minimum length of $1.4\sqrt{R_st_s}$, reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder. The required area of reinforcement shall be at least equal to that indicated by the following formula when Q_s is in compression:

$$A_{rs} = \frac{kQ_sR_s\tan\alpha}{S_sE_1} \qquad (6)$$

At the small end of the cone-to-cylinder juncture, the $PR_s/2$ term is in compression. When f_2 is in tension and the quantity is larger than the $PR_s/2$ term, the design shall be in accordance with U-2(g). The calculated localized stresses at the discontinuity shall not exceed the stress values specified in 1-5(g)(1) and 1-5(g)(2).

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{es} = 0.55\left[\sqrt{D_st_s}\left(t_s - t\right) + \sqrt{\left(D_st_c/\cos\left[\alpha\right]\right)}\left(t_c - t_r\right)\right] \qquad (7)$$

Any additional area of stiffener which is required shall be situated within a distance of $\sqrt{R_st_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.25\sqrt{R_st_s}$ from the junction.

(2) For cones attached to flat covers, flanges, or other components where the length of cylinder, if present, is less than $1.4\sqrt{R_st_s}$, the required reinforcement shall be at least equal to that indicated by the following formula:

$$A_{rS} = \frac{kQ_sD_s}{2S_sE_2}\tan\alpha \qquad (8)$$

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eS} = 0.55\sqrt{\left(D_st_s/\cos\left[\alpha\right]\right)}\left(t_s - t_r\right) \qquad (9)$$

Any additional area of reinforcement that is required shall be added to the cone or the flange.

(3) When the cone-to-cylinder or knuckle-to-cylinder juncture is a line of support, the moment of inertia for a stiffening ring at the small end shall be determined by the procedure in Steps 1 through 8 below.

For cones attached to flat covers, flanges, or other components where the length of the cylinder, if present, is less than $1.4\sqrt{R_st_s}$, length L_s in the formulas for A_{TS} and N shall be zero.

Step 1. Assuming that the shell has been designed and D_s, L_s, and t are known, select a member to be used for the stiffening ring and determine cross-sectional area A_{TS}. Then calculate factor B using the following formula. If F_s is a negative number, the design shall be in accordance with U-2(g):

$$B = \frac{3}{4}\left(\frac{F_sD_s}{A_{TS}}\right)$$

where

$$F_s = PN + f_2\tan\alpha$$

$$N = \frac{R_s\tan\alpha}{2} + \frac{L_s}{2} + \frac{R_L{}^2 - R_s{}^2}{6R_s\tan\alpha}$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5 below.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E_x$. For value of B above the material/temperature line for the design temperature, the design shall be either per U-2(g) or by changing the cone or cylinder configuration, stiffening ring location on the shell, and/or reducing the axial compressive force to reduce the B value to below or at the material/temperature line for the design temperature. For values of B having multiple values of A, such as when B falls on a horizontal portion of the curve, the smallest value of A shall be used.

Step 6. Compute the value of the required moment of inertia from the equations for I_s or I'_s.

For the circumferential stiffening ring only,

$$I_s = \frac{AD_s^2 A_{TS}}{14.0}$$

For the shell-cone or ring-shell-cone section,

$$I'_s = \frac{AD_s^2 A_{TS}}{10.9}$$

Step 7. Determine the available moment of inertia of the ring only I or the shell-cone or ring-shell-cone I'.

Step 8. When the ring only is used,

$$I \geq I_s$$

and when the shell-cone or ring-shell-cone is used:

$$I' \geq I'_s$$

If the equation is not satisfied, a new section with a larger moment of inertia must be selected, and the calculation shall be done again until the equation is met.

The requirements of UG-29(b), UG-29(c), UG-29(d), UG-29(e), and UG-29(f) and UG-30 are to be met in attaching stiffening rings to the shell.

(d) Reducers not described in UG-36(e)(5), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (e).

(e) When the half-apex angle α is greater than 60 deg (1.1 rad), cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on special analysis, such as the beam-on-elastic-foundation analysis of Timoshenko, Hetenyi, or Watts and Lang. See U-2(g). The effect of shell and cone buckling on the required area and moment of inertia at the joint is to be taken into consideration in the analysis. When such an analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values:

(1) Membrane hoop stress plus average discontinuity hoop stress shall not be greater than 1.5S.

(2) Membrane longitudinal stress plus discontinuity longitudinal stress due to bending shall not be greater than S_{PS} [see UG-23(e)], where the "average discontinuity hoop stress" is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson's ratio times the longitudinal stress at the surfaces.

(25)

MANDATORY APPENDIX 2 RULES FOR BOLTED FLANGE CONNECTIONS WITH RING TYPE GASKETS

2-1 GENERAL

(a) The rules in this Appendix cover the minimum requirements for design of bolted flange connections with gaskets that are entirely within the circle enclosed by the bolt holes and with no contact outside this circle and are to be used in conjunction with the applicable requirements in Subsections A, B, C, and D of this Division.

(1) The hub thickness of weld neck flanges and the design of components in the bolted flange connection, other than the flange, shall be in accordance with the applicable rules of Subsection A and the Mandatory Appendices.

(2) These rules are not to be used for the determination of the thickness of tubesheets integral with a bolting flange as illustrated in Figure UW-13.2, sketches (h) through (l) or Figure UW-13.3, sketch (c).

(3) Nonmandatory Appendix S provides discussion on design considerations for bolted flange connections.

(4) Design requirements for bolted flange connections in 2-4 and Section VIII, Division 2, Part 4.16 shall be used in lieu of those previously listed in this Appendix. Tables 2-1-1 and 2-1-2 list the new locations for requirements formerly located in this Division.

(5) The Section VIII, Division 1 design requirements listed in Table 2-1-3 shall be used in lieu of the corresponding Section VIII, Division 2 requirements referenced in Part 4.16.

(6) When this Appendix is applied for design, the applicable section of Section VIII, Division 2, Part 4.16 shall be used in accordance with UG-16(a) and Mandatory Appendix 46.

(7) For vessels in lethal service or when specified by the user or the user's designated agent, the maximum bolt spacing, B_{smax}, and the bolt spacing correction factor, B_{sc}, shall be applied in calculating the flange moment for internal pressure.

(8) Successful service experience may be used as an alternative to the flange rigidity rules for fluid services that are nonlethal and nonflammable and designed within the temperature range of −20°F to 366°F (−29°C to 186°C) without exceeding design pressures of 150 psi (1 035 kPa).

(b) It is recommended that bolted flange connections conforming to the standards listed in UG-44(a) be used for connections to external piping. These standards may be used for other bolted flange connections and dished covers within the limits of size in the standards and the pressure–temperature ratings permitted in UG-44(a). The ratings in these standards are based on the hub dimensions given or on the minimum specified thickness of flanged fittings of integral construction. Flanges fabricated from rings may be used in place of the hub flanges in these standards provided that their strength, calculated by the rules in this Appendix, is not less than that calculated for the corresponding size of hub flange.

(c) Except as otherwise provided in (b), bolted flange connections for unfired pressure vessels shall satisfy the requirements in this Appendix.

(d) The rules of this Appendix should not be construed to prohibit the use of other types of flanged connections, provided they are designed in accordance with good engineering practice and the method of design is acceptable to the Inspector. Some examples of flanged connections that might fall in this category are as follows:

(1) flanged covers as shown in Mandatory Appendix 1, Figure 1-6

(2) bolted flanges using full-face gaskets

(3) flanges using means other than bolting to restrain the flange assembly against pressure and other applied loads

2-2 MATERIALS

(a) Materials used in the construction of bolted flange connections shall comply with the requirements given in UG-4 through UG-14.

(b) Flanges made from ferritic steel and designed in accordance with this Appendix shall be full-annealed, normalized, normalized and tempered, or quenched and tempered when the thickness of the flange, t (see Section VIII, Division 2, Figure 4.16.1), exceeds 3 in. (75 mm).

(c) Material on which welding is to be performed shall be proved of good weldable quality. Satisfactory qualification of the welding procedure under Section IX is considered as proof. Welding shall not be performed on steel that has a carbon content greater than 0.35%. All welding on flange connections shall comply with the requirements for postweld heat treatment given in this Division.

(d) Hubbed flanges shall not be machined from plate or bar material [except as permitted in UG-14(c)] unless the material has been formed into a ring and the following additional conditions are met:

Table 2-1-1
Paragraph Cross-Reference List

Division 1 Paragraph	Division 2 Paragraph
2-3, Notation — deleted	4.16.13
2-4, Circular Flange Types	4.16.3
2-5, Bolts Loads — deleted	4.16.2 and 4.16.6
2-6, Flange Moment — deleted	4.16.7
2-7, Calculation of Flange Stresses — deleted	4.16.7
2-8, Allowable Flange Design Stress — deleted	4.16.7
2-9, Split Loose Flanges — deleted	4.16.8
2-10, Noncircular Shaped Flanges with Circular Bore — deleted	4.16.9
2-11, Flanges Subject to External Pressure — deleted	4.16.7
2-12, Flanges With Nut Stops — deleted	4.16.10
2-13, Reverse Flanges — deleted	4.16.3.2 and 4.16.7
2-14, Flange Rigidity — deleted	4.16.7

(1) In a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange. (This is not intended to imply that the original plate surface should be present in the finished flange.)

(2) The joints in the ring are welded butt joints that conform to the requirements of this Division. Thickness to be used to determine postweld heat treatment and radiography requirements shall be the lesser of

$$t \text{ or } \frac{(A - B)}{2}$$

where these symbols are as defined in 2-3.

(3) The back of the flange and the outer surface of the hub are examined by either the magnetic particle method as per Mandatory Appendix 6 or the liquid penetrant method as per Mandatory Appendix 8.

(e) Bolts, studs, nuts, and washers shall comply with the requirements in this Division. It is recommended that bolts and studs have a nominal diameter of not less than $^1/_2$ in. (13 mm). If bolts or studs smaller than $^1/_2$ in. (13 mm) are used, ferrous bolting material shall be of alloy steel. Precautions shall be taken to avoid overstressing small-diameter bolts.

2-4 CIRCULAR FLANGE TYPES

(a) Integral-Type Flanges. Integral-type flanges are addressed in Section VIII, Division 2, 4.16.3.1(a).

(b) Welded Slip-on–Type Flanges. Welded slip-on–type flanges are addressed in Section VIII, Division 2, 4.16.3.1(b).

(c) Loose-Type Flanges. Loose-type flanges are addressed in Section VIII, Division 2, 4.16.3.1(c).

(d) Reverse-Type Flanges

(1) Integral-Type Reverse Flange. The shell-to-flange attachment of integral-type reverse flanges may be attached as shown in Section VIII, Division 2, Table 4.2.9, details (6) through (10), or Figure 2-4, as well as Figure UW-13.2, sketches (a) and (b). The requirements of 2-4(c) apply to Figure 2-4, as well as Figure UW-13.2, sketches (a) and (b).

(2) Welded Slip-on–Type Reverse Flange. The shell-to-flange attachment of welded slip-on-type reverse flanges may be attached as shown in Section VIII, Division 2, Table 4.2.9, details (2) and (4), or Figure 2-4, as well as Figure UW-13.2, sketches (c) and (d). When Figure UW-13.2, sketches (c) and (d) are used, the maximum wall thickness of the shell shall not exceed $^3/_8$ in. (10 mm), and the maximum design metal temperature shall not exceed 650°F (340°C).

2-15 QUALIFICATION OF ASSEMBLY PROCEDURES AND ASSEMBLERS

It is recommended that flange joints designed to this Appendix be assembled by qualified procedures and by qualified assemblers. ASME PCC-1 may be used as a guide.

Table 2-1-2
Figure and Table Cross-Reference List

Topic	Division 1	Division 2
Loose-type flange	Figure 2-4, sketch (1) — deleted	Figure 4.16.5
	Figure 2-4, sketch (1a) — deleted	Table 4.2.9, detail 5
	Figure 2-4, sketches (2) and (2a) — deleted	Screwed Type Flanges — deleted
	Figure 2-4, sketch (3) — deleted	Figure 4.16.2; Table 4.2.9, detail 1 (welded slip-on flange)
	Figure 2-4, sketch (3a) — deleted	Figure 4.16.1(b); Table 4.2.9, detail 2 (integral flange)
	Figure 2-4, sketch (4) — deleted	Figure 4.16.2; Table 4.2.9, detail 3 (welded slip-on flange)
	Figure 2-4, sketch (4a) — deleted	Figure 4.16.1(b); Table 4.2.9, detail 4 (integral flange)
	Figure 2-4, sketch (4b) — deleted	Figure 4.16.1(b); Table 4.2.9, detail 11 (integral flange)
	Figure 2-4, sketch (4c) — deleted	Figure 4.16.2; Table 4.2.9, detail 12 (welded slip-on flange)
Integral-type flange	Figure 2-4, sketch (5) — deleted	Figure 4.16.1(c)
	Figure 2-4, sketch (6) — deleted	Figure 4.16.1(d); Table 4.2.9, detail 6
	Figure 2-4, sketch (6a) — deleted	Figure 4.16.1(e); Table 4.2.9, detail 7
	Figure 2-4, sketch (6b) — deleted	Figure 4.16.1(f); Table 4.2.9, detail 8
	Figure 2-4, sketch (7) — deleted	Figure 4.16.1(a); Table 4.2.9, detail 9
Optional type flange	Figure 2-4, sketches (8), (8A), (9), (9a), (10), (10a), and (11) — deleted	Optional type flange — deleted
Flange with nut stop	Figure 2-4, sketch (12)	Figure 4.16.3
	Figure 2-4, sketch (12a)	Figure 4.16.4
Minimum contact width	Table 2-4	Table 4.16.2
Gasket factors	Table 2-5.1	Table 4.16.1
Effective gasket width	Table 2-5.2	Table 4.16.3
Location of gasket reaction	Table 2-5.2	Figure 4.16.8
Moment arms for flange loads	Table 2-6	Table 4-16.6
Terms involving K	Figure 2-7.1	Table 4.16.4
Flange factors in formula form	Table 2-7.1	Table 4.16.5
Values of F for integral flange	Figure 2-7.2 — deleted	Table 4.16.5
Values of V for integral flange	Figure 2-7.3 — deleted	Table 4.16.5
Values of F_L for loose flange	Figure 2-7.4 — deleted	Table 4.16.5
Values of V_L for loose flange	Figure 2-7.5 — deleted	Table 4.16.5
Values of f	Figure 2-7.6 — deleted	Table 4.16.5
Integral-type reverse flanges	Figure 2-13.1	Figure 4.16.6(a)
Loose-ring reverse flange	Figure 2-13.2	Figure 4.16.7
Flange rigidity	Table 2-14	Table 4.16.10

Table 2-1-3
Division 2 Cross-Reference List to Division 1 Requirements

Topic	Division 2 Paragraph	Division 2 Reference	Division 1
Flange and pipe fittings	4.16.1.3	4.1.11	UG-44(a)
Design rules for flange joints	4.16.1.4	Part 5	2-1(d), U-2(g)
Flange materials	4.16.4	Part 3	2-2
Joint assembly procedure	4.16.11	...	2–15
Evaluation of external forces and moments for flanged joints with standard flanges	4.16.12	4.1.11	UG-44(b)

MANDATORY APPENDIX 3
DEFINITIONS

3-1 INTRODUCTION

This Appendix contains definitions of terms generally used in this Division. Definitions relating to specific applications, such as for layered vessels, may be found in related parts of this Division.

(25) 3-2 DEFINITIONS OF TERMS

acceptance by the Inspector, accepted by the Inspector: an indication that the Inspector has reviewed a subject in accordance with the Inspector's duties as required by the rules of this Division and after such review is able to sign the Certificate of Inspection for the applicable Manufacturer's Data Report Form.

ASME Designated Organization: see ASME CA-1.

ASME designee: see ASME CA-1.

basic material specification: a description of the identifying characteristics of a material (product form, ranges of composition, mechanical properties, methods of production, etc.) together with the sampling, testing, and examination procedures to be applied to production lots of such material to verify acceptable conformance to the intended characteristics.

bolt: a threaded fastener with a head on one end.

calculated test pressure: the requirements for determining the test pressure based on calculations are outlined in UG-99(c) for the hydrostatic test and in UG-100(b) for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design equations, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values given in Section II, Part D, Subpart 1 for the temperature of the test.

Certificate of Authorization: a document issued by the Society that authorizes the use of the ASME Certification Mark and appropriate designator for a specified time and for a specified scope of activity.

certificate of compliance: a document that states that the material represented has been manufactured, sampled, tested, and inspected in accordance with the requirements of the material specification (including year of issue) and any other requirements specified in the purchase order or contract shown on the certificate, and has been found to meet such requirements. This document may be combined with a Material Test Report as a single document.

Certification Designator (Designator): the symbol used in conjunction with the Certification Mark for the scope of activity described in a Manufacturer's Certificate of Authorization.

Certification Mark: An ASME symbol identifying a product as meeting Code Requirements.

Certification Mark Stamp: a metallic stamp issued by the Society for use in impressing the Certification Mark.

clad vessel: a vessel made from a base material having a corrosion resistant material either integrally bonded or weld metal overlaid to the base of less resistant material.

completed pressure vessel: an assemblage of pressure vessel parts of which no further welding, assembly, or testing is required, and to which a Certification Mark and Designator has been applied and for which Nonmandatory Appendix W, Form U-1 or Form U-1A has been completed.

construction: an all-inclusive term comprising material, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

designer: an individual who is qualified to design pressure vessels in accordance with the rules of this Division by demonstrated knowledge in Code requirements and proficiency in selecting correct design formulas and appropriate values to be used when preparing the design of a pressure vessel.

design pressure: the pressure used in the design of a vessel component together with the coincident design metal temperature, for the purpose of determining the minimum permissible thickness or physical characteristics of the different zones of the vessel. When applicable, static head shall be added to the design pressure to determine the thickness of any specific zone of the vessel (see UG-21).

design temperature: see UG-20.

efficiency of a welded joint: the efficiency of a welded joint is expressed as a numerical (decimal) quantity and is used in the design of a joint as a multiplier of the appropriate allowable stress value taken from the applicable table in Section II, Part D, Subpart 1 (see UW-12).

full vacuum (FV): a condition where the internal absolute pressure is 0 psi (0 kPa) and the external absolute pressure on the vessel is 15 psi (103 kPa)(see UG-116).

joints: for the purpose of this Division, the following definitions are applicable:

(a) angle joint: a joint between two members located in intersecting planes with an angle greater than 30 deg but less than 90 deg.

(b) butt joint: a joint between two members located in intersecting planes between 0 deg and 30 deg, inclusive.

(c) corner joint: a joint between two members located in intersecting planes at approximately 90 deg.

layered vessel: a vessel having a shell and/or heads made up of two or more separate layers.

lined vessel: a vessel having a corrosion resistant lining attached intermittently to the vessel wall.

liquid penetrant examination (PT): a method of nondestructive examination that provides for the detection of imperfections open to the surface in ferrous and nonferrous materials that are nonporous. Typical imperfections detectable by this method are cracks, seams, laps, cold shuts, and laminations.

magnetic particle examination (MT): a method of detecting cracks and similar imperfections at or near the surface in iron and the magnetic alloys of steel. It consists of properly magnetizing the material and applying finely divided magnetic particles that form patterns indicating the imperfections.

material: any substance or product form covered by a specification in Section II, Part A, Part B, or Part C, or any other substance or product form permitted for use in pressure vessel construction by this Division.

material manufacturer: the organization responsible for the production of products meeting the requirements of the material specification, and accepting the responsibility for any statements or data in any required certificate of compliance or Material Test Report representing the material.

Material Test Report: a document in which the results of tests, examinations, repairs, or treatments required by the material specification to be reported are recorded, including those of any supplementary requirements or other requirements stated in the order for the material. This document may be combined with a certificate of compliance as a single document.

maximum allowable stress value: the maximum unit stress permissible for any specified material that may be used in the design equations given in this Division (see UG-23).

maximum allowable working pressure: the maximum gage pressure permissible at the top of a completed vessel in its normal operating position at the designated coincident temperature for that pressure. This pressure is the least of the values for the internal or external pressure to be determined by the rules of this Division for any of the pressure boundary parts, including the static head thereon, using nominal thicknesses exclusive of allowances for corrosion and considering the effects of any combination of loadings listed in UG-22 that are likely to occur (see UG-98) at the designated coincident temperature [see UG-20(a)]. It is the basis for the pressure setting of the pressure-relieving devices protecting the vessel. The design pressure may be used in all cases in which calculations are not made to determine the value of the maximum allowable working pressure.

membrane stress: the component of normal stress that is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

nominal pipe size [NPS (DN)]: nominal pipe size as used throughout this Division is defined as the pipe outside diameter for a given pipe size in accordance with ASME B36.10M.

normal operation: operation within the design limits for which the vessel has been stamped. [See UG-116(a).] Any coincident pressure and temperature during a specific operation are permissible, provided they do not constitute a more severe condition than that assumed in the design of the vessel.

operating or working temperature: the temperature that will be maintained in the metal of the part of the vessel being considered for the specified operation of the vessel (see UG-20 and UG-23).

operating pressure: the pressure at the top of a vessel at which it normally operates. It shall not exceed the maximum allowable working pressure, and it is usually kept at a suitable level below the setting of the pressure-relieving devices to prevent their frequent opening (see Nonmandatory Appendix M, M-9).

porosity: gas pockets or voids in metal.

pressure vessel part: an integral piece of the pressure vessel that is required to contain the specified design pressure (internal or external) and/or the hydrostatic or pneumatic test pressure of the contents of the pressure vessel within the allowable stress limits of this Division. If this part were completely removed, the pressure vessel would not be able to contain the design and/or hydrostatic or pneumatic test pressure within the allowable stress limits. Excess thickness and material extensions are included in the pressure part.

primary stress: a stress developed by the imposed loading that is necessary to satisfy the simple laws of equilibrium of external and internal forces and moments. Primary stress can be either membrane or bending stress.

Primary membrane stress may be of two types: general and local. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. A local primary membrane stress is one that is produced by pressure or other mechanical loading and that is associated with a primary and/or discontinuity effect. Examples of primary stress are

(a) general membrane stress in a circular cylinder or a spherical shell due to internal pressure or to distributed loads;

(b) bending stress in the central portion of a flat head due to pressure.

radiographic examination (RT): a method of detecting imperfections in materials by passing X-ray or nuclear radiation through the material and presenting their image on a recording medium.

replacement or repair parts: parts intended for replacement or repair activities on an existing pressure vessel. The existing pressure vessel shall be marked and certified to this Code Edition or a previous Code Edition or Addenda of this Division. Construction of parts shall be to a currently accepted Edition of the Code [see 43-1(a)]. Design was either performed to the original certifying Edition or Addenda during original construction or performed to a currently accepted Edition of the Code [see 43-1(a)].

spiral weld: a weld joint having a helical seam [see UW-3(a)].

stationary pressure vessel: a pressure vessel to be installed and operated as a fixed geographical location.

stud: a threaded fastener without a head, with threads on one end or both ends, or threaded full length.

thickness of vessel wall:

(a) design thickness: the sum of the required thickness and the corrosion allowance (see UG-25).

(b) required thickness: that computed by the equations in this Division before corrosion allowance is added (see UG-22).

(c) nominal thickness: except as defined in UW-40.6 and modified in UW-11(g), the nominal thickness is the thickness selected as commercially available, and supplied to the Manufacturer. For plate material, the nominal thickness shall be, at the Manufacturer's option, either the thickness shown on the Material Test Report {or material Certificate of Compliance [see UG-93.1(a)] before forming, or the measured thickness of the plate at the joint or location under consideration.

ultrasonic examination (UT): a method for detecting imperfections in materials by passing ultrasonic vibrations (frequencies normally 1 MHz to 5 MHz) through the material.

vessel Manufacturer: any Manufacturer who constructs an item such as a pressure vessel, vessel component, or part in accordance with rules of this Division and who holds an ASME Certificate of Authorization to apply the Certification Mark and the appropriate Designator to such an item.

MANDATORY APPENDIX 4
ROUNDED INDICATIONS CHARTS ACCEPTANCE STANDARD FOR RADIOGRAPHICALLY DETERMINED ROUNDED INDICATIONS IN WELDS

4-1 APPLICABILITY OF THESE STANDARDS

These standards are applicable to ferritic, austenitic, and nonferrous materials.

Table 4-1

Thickness, t, in.	Maximum Size of Acceptable Rounded Indication, in. — Random	Maximum Size of Acceptable Rounded Indication, in. — Isolated	Maximum Size of Nonrelevant Indication, in.
Customary Units			
Less than $^1/_8$	$^1/_4\ t$	$^1/_3\ t$	$^1/_{10}\ t$
$^1/_8$	0.031	0.042	0.015
$^3/_{16}$	0.047	0.063	0.015
$^1/_4$	0.063	0.083	0.015
$^5/_{16}$	0.078	0.104	0.031
$^3/_8$	0.091	0.125	0.031
$^7/_{16}$	0.109	0.146	0.031
$^1/_2$	0.125	0.168	0.031
$^9/_{16}$	0.142	0.188	0.031
$^5/_8$	0.156	0.210	0.031
$^{11}/_{16}$	0.156	0.230	0.031
$^3/_4$ to 2, incl.	0.156	0.250	0.031
Over 2	0.156	0.375	0.063
SI Units			
Thickness, t, mm	**Maximum Size of Acceptable Rounded Indication, mm — Random**	**Maximum Size of Acceptable Rounded Indication, mm — Isolated**	**Maximum Size of Nonrelevant Indication, mm**
Less than 3	$^1/_4\ t$	$^1/_3\ t$	$^1/_{10}\ t$
3	0.79	1.07	0.38
5	1.19	1.60	0.38
6	1.60	2.11	0.38
8	1.98	2.64	0.79
10	2.31	3.18	0.79
11	2.77	3.71	0.79
13	3.18	4.27	0.79
14	3.61	4.78	0.79
16	3.96	5.33	0.79
17	3.96	5.84	0.79
19.0 to 50, incl.	3.96	6.35	0.79
Over 50	3.96	9.53	1.60

GENERAL NOTE: This Table contains examples only.

4-2 TERMINOLOGY

(a) Rounded Indications. Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any imperfection in the weld, such as porosity, slag, or tungsten.

(b) Aligned Indications. A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

(c) Thickness t. t is the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

4-3 ACCEPTANCE CRITERIA

(a) Image Density. Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

(b) Relevant Indications. (See Table 4-1 for examples.) Only those rounded indications which exceed the following dimensions shall be considered relevant.

(1) $^1/_{10}t$ for t less than $^1/_8$ in. (3 mm)

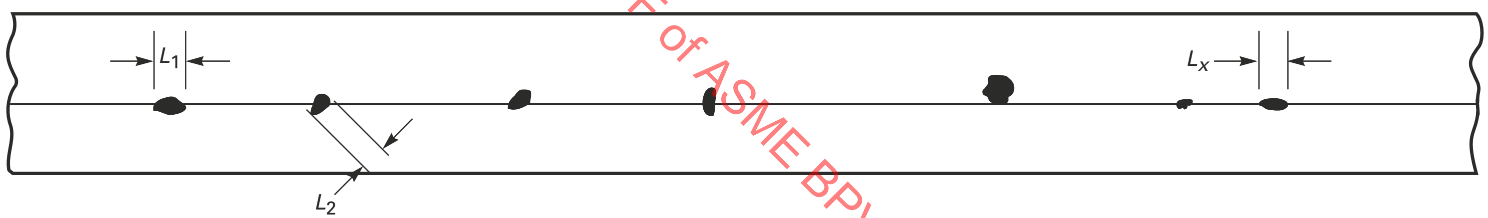
(2) $^1/_{64}$ in. for t from $^1/_8$ in. to $^1/_4$ in. (3 mm to 6 mm), incl.

(3) $^1/_{32}$ in. for t greater than $^1/_4$ in. to 2 in. (6 mm to 50 mm), incl.

(4) $^1/_{16}$ in. for t greater than 2 in. (50 mm)

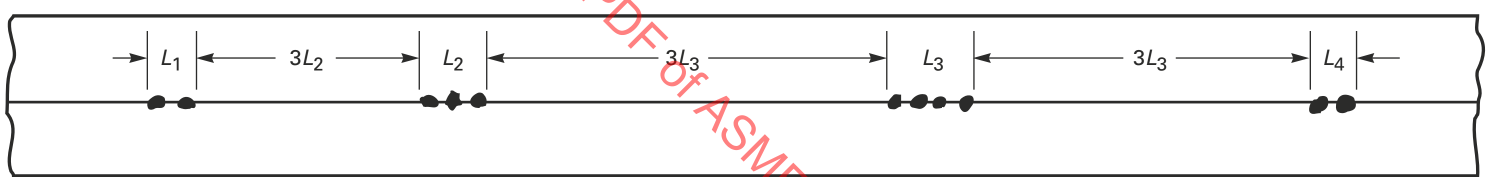
(c) Maximum Size of Rounded Indication. (See Table 4-1 for examples.) The maximum permissible size of any indication shall be $^1/_4t$, or $^5/_{32}$ in. (4 mm), whichever is smaller; except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be $^1/_3t$, or $^1/_4$ in. (6 mm), whichever is less. For t greater than 2 in. (50 mm) the maximum permissible size of an isolated indication shall be increased to $^3/_8$ in. (10 mm).

Figure 4-1
Aligned Rounded Indications



GENERAL NOTE: Sum of L_1 to L_x shall be less than t in a length of $12t$.

Figure 4-2
Groups of Aligned Rounded Indications



Maximum Group Length

L = $^1/_4$ in. (6 mm) for t less than $^3/_4$ in. (19 mm)
L = $^1/_3 t$ for t $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm)
L = $^3/_4$ in. (19 mm) for t greater than $2^1/_4$ in. (57 mm)

Minimum Group Spacing

$3L$ where L is the length of the longest adjacent group being evaluated

GENERAL NOTE: Sum of the group lengths shall be less than t in a length of $12t$.

(d) Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$. See Figure 4-1. The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure 4-2.

(e) Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

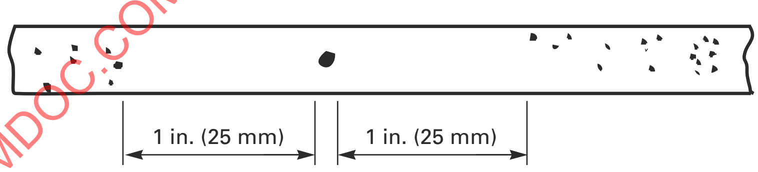
(f) Rounded Indication Charts. The rounded indications characterized as imperfections shall not exceed that shown in the charts. The charts in Figures 4-3 through 4-8 illustrate various types of assorted, randomly dispersed and clustered rounded indications for different weld thicknesses greater than $\frac{1}{8}$ in. (3 mm). These charts represent the maximum acceptable concentration limits for rounded indications. The charts for each thickness range represent full-scale 6 in. (150 mm) radiographs, and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

(g) Weld Thickness t Less Than $\frac{1}{8}$ in. (3 mm). For t less than $\frac{1}{8}$ in. (3 mm) the maximum number of rounded indications shall not exceed 12 in a 6 in. (150 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. (150 mm) in length.

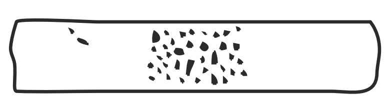
(h) Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (150 mm) length weld.

Figure 4-3
Charts for t Equal to $\frac{1}{8}$ in. to $\frac{1}{4}$ in. (3 mm to 6 mm), Inclusive

(a) Random Rounded Indications [See Note (1)]



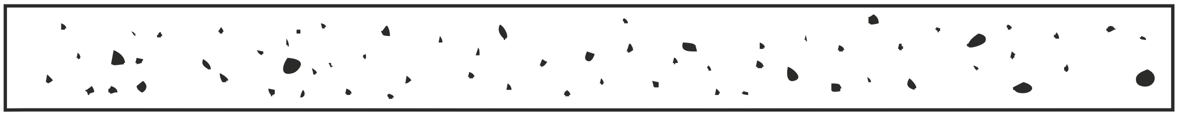
(b) Isolated Indication [See Note (2)]



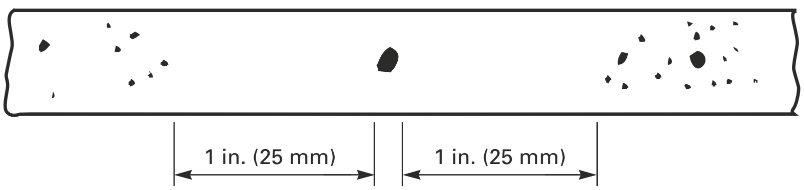
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

Figure 4-4
Charts for *t* Over ¼ in. to ⅜ in. (6 mm to 10 mm), Inclusive



(a) Random Rounded Indications [See Note (1)]

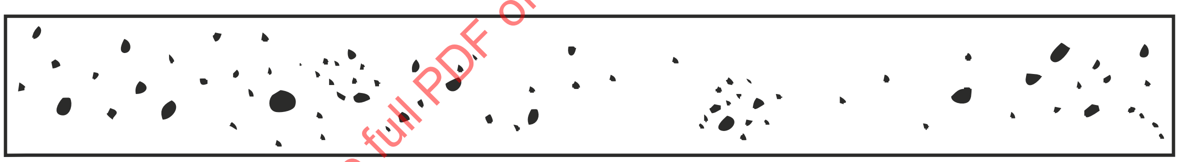


(b) Isolated Indication [See Note (2)]

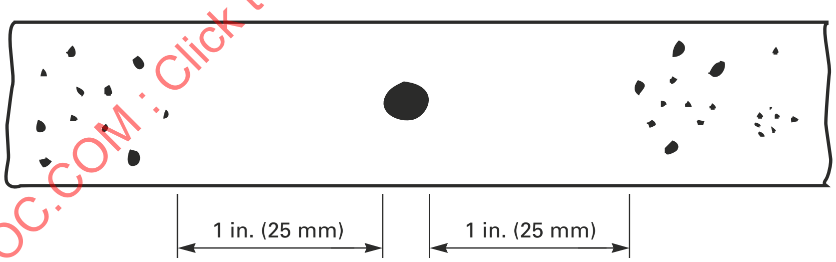
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

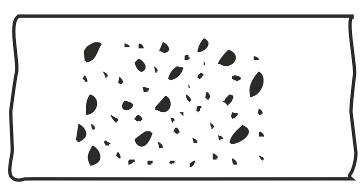
Figure 4-5
Charts for *t* Over ⅜ in. to ¾ in. (10 mm to 19 mm), Inclusive



(a) Random Rounded Indications [See Note (1)]



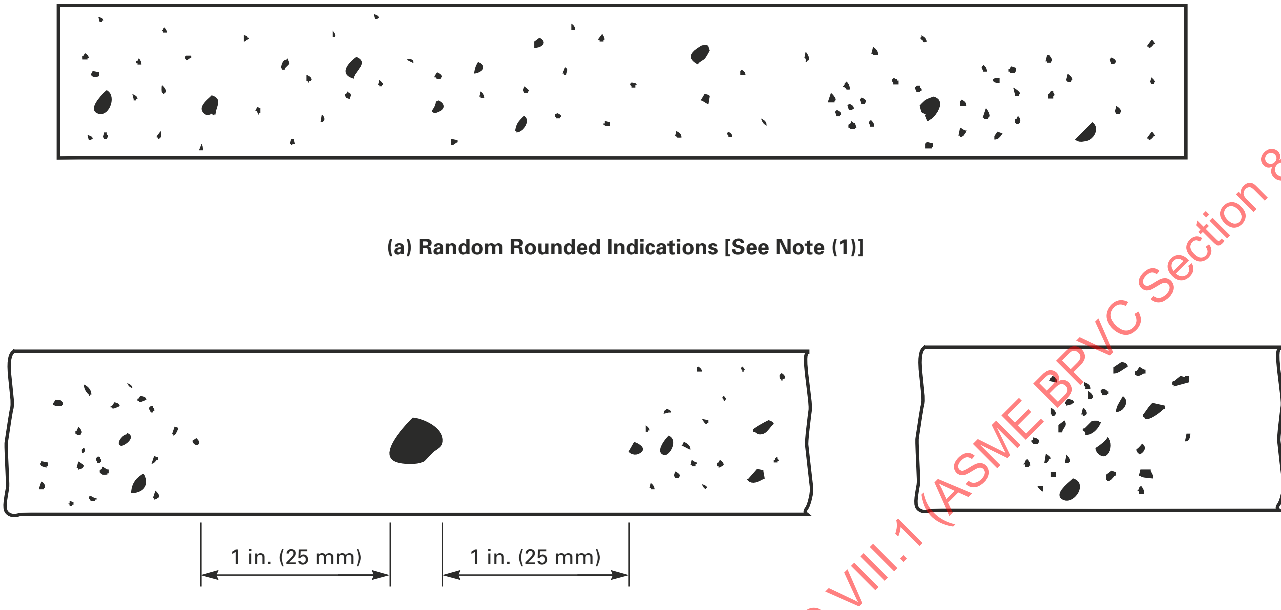
(b) Isolated Indication [See Note (2)]



(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

Figure 4-6
Charts for t Over $\frac{3}{4}$ in. to 2 in. (19 mm to 50 mm), Inclusive



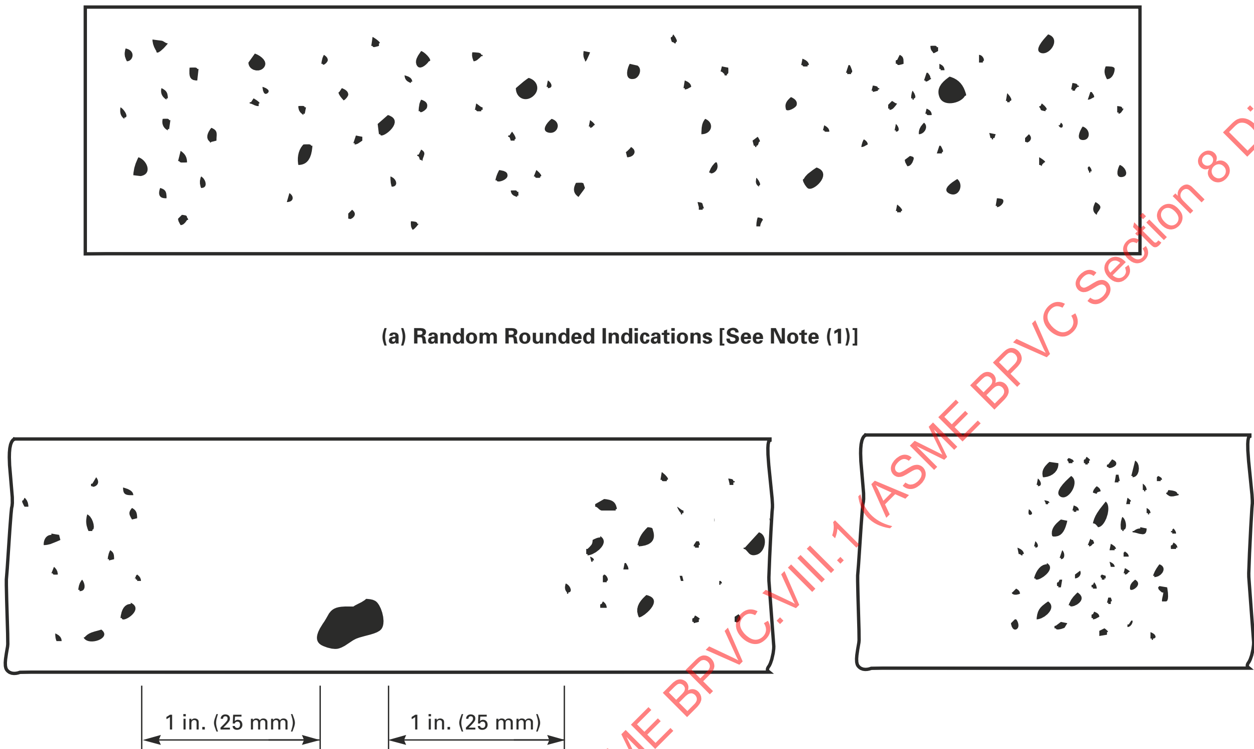
(a) Random Rounded Indications [See Note (1)]

(b) Isolated Indication [See Note (2)]

(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

Figure 4-7
Charts for *t* Over 2 in. to 4 in. (50 mm to 100 mm), Inclusive



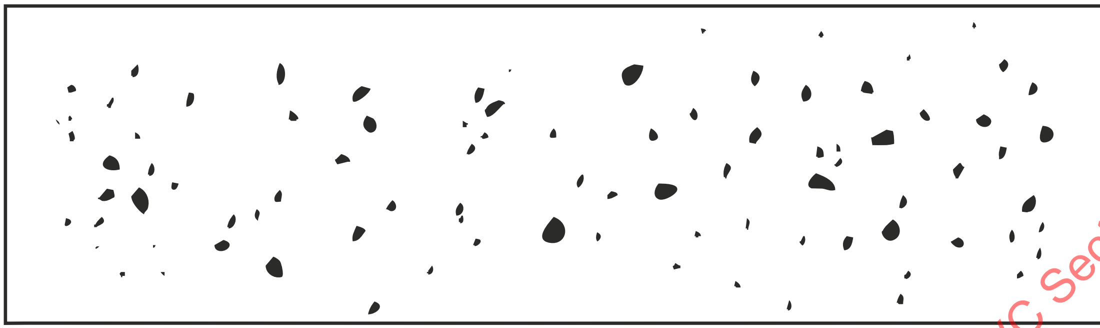
(a) Random Rounded Indications [See Note (1)]

(b) Isolated Indication [See Note (2)]

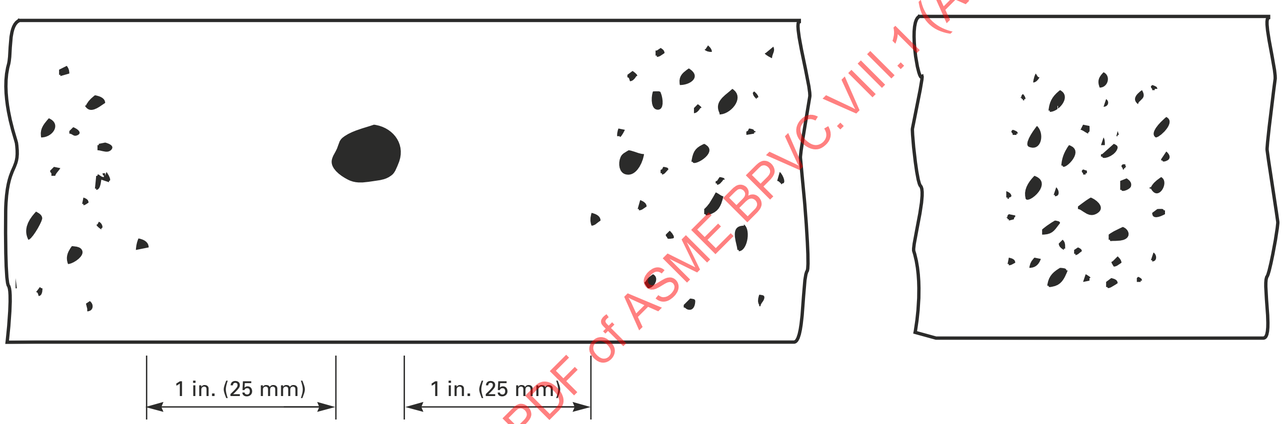
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

Figure 4-8
Charts for *t* Over 4 in. (100 mm)



(a) Random Rounded Indications [See Note (1)]



(b) Isolated Indication [See Note (2)]

(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

MANDATORY APPENDIX 5 FLEXIBLE SHELL ELEMENT EXPANSION JOINTS (25)

Information formerly in this Appendix has been moved to Part UEJ.

MANDATORY APPENDIX 6
METHODS FOR MAGNETIC PARTICLE EXAMINATION (MT)

6-1 SCOPE

(a) This Appendix provides for procedures which shall be followed whenever magnetic particle examination is specified in this Division.

(b) Section V, Article 7 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.

(c) Magnetic particle examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150

(d) Documentation showing that the required examinations have been performed and that the results are acceptable shall be made available to the Inspector.

(25) 6-2 CERTIFICATION OF COMPETENCY FOR NONDESTRUCTIVE EXAMINATION PERSONNEL

The Manufacturer shall certify that each magnetic particle examiner meets the following requirements:

(a) The examiner has vision, with correction if necessary, to enable the examiner to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 12 in., and is capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) The examiner is competent in the techniques of the magnetic particle examination method for which the examiner is certified, including making the examination and interpreting and evaluating the results, except that where the examination method consists of more than one operation, the examiner may be certified as being qualified only for one or more of these operations.

6-3 EVALUATION OF INDICATIONS

Indications will be revealed by retention of magnetic particles. All such indications are not necessarily imperfections, however, since excessive surface roughness, magnetic permeability variations (such as at the edge of heat-affected zones), etc., may produce similar indications.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications which have any dimension greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant.

(a) A linear indication is one having a length greater than three times the width.

(b) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

(c) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

6-4 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division.

All surfaces to be examined shall be free of:

(a) relevant linear indications;

(b) relevant rounded indications greater than $^3/_{16}$ in. (5 mm);

(c) four or more relevant rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less, edge to edge.

6-5 REPAIR REQUIREMENTS

The defect shall be removed or reduced to an imperfection of acceptable size. Whenever an imperfection is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of an imperfection, the area shall be cleaned and welding performed in accordance with a qualified welding procedure.

(a) Treatment of Indications Believed Nonrelevant. Any indication which is believed to be nonrelevant shall be regarded as an imperfection unless it is shown by reexamination by the same method or by the use of other nondestructive methods and/or by surface conditioning that no unacceptable imperfection is present.

(b) Examination of Areas From Which Imperfections Have Been Removed. After a defect is thought to have been removed and prior to making weld repairs, the area shall be examined by suitable methods to ensure it has been removed or reduced to an acceptably sized imperfection.

(c) Reexamination of Repair Areas. After repairs have been made, the repaired area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners and reexamined by the magnetic particle method and by all other methods of examination that were originally required for the affected area, except that, when the depth of repair is less than the radiographic sensitivity required, reradiography may be omitted.

MANDATORY APPENDIX 7
EXAMINATION OF STEEL CASTINGS

(25) 7-1 SCOPE

This Appendix covers examination requirements that shall be observed for all steel castings to which a 100% quality factor is to be applied in accordance with UG-24.2.3.2. Except for applications involving lethal service, steel castings made to an accepted standard, such as ASME B16.5, are not required to comply with the provisions of this Appendix.

7-2 EXAMINATION TECHNIQUES

Examination techniques shall be carried out in accordance with the following:

(a) Magnetic particle examinations shall be per Mandatory Appendix 6 except that acceptance standards shall be as given in 7-3(a)(3) of this Appendix.

(b) Liquid penetrant examinations shall be per Mandatory Appendix 8 except that acceptance standards shall be as given in 7-3(a)(4) of this Appendix.

(c) Radiographic examinations shall be per Section V, Article 2 with acceptance standards as given in 7-3(a)(1) or 7-3(b)(3) of this Appendix.

(1) A written radiographic examination procedure is not required. Demonstration of density and image quality indicator (IQI) image requirements on production or technique radiographs shall be considered satisfactory evidence of compliance with Section V, Article 2.

(2) The requirements of Section V, Article 2, T-285 are to be used only as a guide. Final acceptance of radiographs shall be based on the ability to see the prescribed IQI image and the specified hole or the designated wire or a wire IQI.

(d) Ultrasonic examinations shall be per Section V, Article 5 with acceptance standards as given in 7-3(b)(3) of this Appendix.

7-3 EXAMINATION REQUIREMENTS

All steel castings shall be examined in accordance with (a) or (b) as applicable.

(a) All castings having a maximum body thickness less than $4^1/_2$ in. (115 mm) shall be examined as follows:

(1) All critical sections[16] shall be radiographed. For castings having radiographed thicknesses up to 2 in. (51 mm), the radiographs shall be compared to those in ASTM E446, Standard Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness. The maximum acceptable severity levels for imperfections shall be as follows:

Imperfection Category	Maximum Severity Level Thicknesses <1 in.	 Thicknesses 1 in. to <2 in.
A — Gas porosity	1	2
B — Sand and slag	2	3
C — Shrinkage (four types)	1	3
D — Cracks	0	0
E — Hot tears	0	0
F — Inserts	0	0
G — Mottling	0	0

For castings having radiographed thicknesses from 2 in. to $4^1/_2$ in. (51 mm to 114 mm), the radiographs shall be compared to those in ASTM E186, Standard Reference Radiographs for Heavy-Walled [2 to $4^1/_2$ in. (50.8 to 114 mm)] Steel Castings. The maximum acceptable severity levels for imperfections shall be as follows:

Imperfection Category	Maximum Severity Level
A — Gas porosity	2
B — Sand and slag inclusions	2
C — Shrinkage	
Type 1	1
Type 2	2
Type 3	3
D — Cracks	0
E — Hot tear	0
F — Inserts	0

(2) All surfaces including machined gasket seating surfaces shall be examined by the magnetic particle or the liquid penetrant method. When the casting specification requires heat treatment, these examinations shall be conducted after that heat treatment.

(3) Surface indications determined by magnetic particle examination shall be compared with those indicated in ASTM E125, Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings, and shall be removed if they exceed the following limits:

	Type	Degree
I.	Linear discontinuities (hot tears and cracks)	All
II.	Shrinkage	2
III.	Inclusions	3
IV.	Chills and chaplets	1
V.	Porosity	1

(4) Surface indications determined by liquid penetrant examination are unacceptable if they exceed the following limits:

(-a) all cracks and hot tears;

(-b) any group of more than six linear indications other than those in (-a) above in any rectangular area of $1^1/_2$ in. × 6 in. (38 mm × 150 mm) or less or any circular area having a diameter of $3^1/_2$ in. (88 mm) or less, these areas being taken in the most unfavorable location relative to the indications being evaluated;

(-c) other linear indications more than $^1/_4$ in. (6 mm) long for thicknesses up to $^3/_4$ in. (19 mm) inclusive, more than one-third of the thickness in length for thicknesses from $^3/_4$ in. to $2^1/_4$ in. (19 mm to 57 mm), and more than $^3/_4$ in. (19 mm) long for thicknesses over $2^1/_4$ in. (57 mm) (aligned acceptable imperfections separated from one another by a distance equal to the length of the longer imperfection are acceptable);

(-d) all indications of nonlinear imperfections which have any dimension exceeding $^3/_{16}$ in. (5 mm).

(5) When more than one casting of a particular design is produced, each of the first five shall be examined to the full extent prescribed herein. When more than five castings are being produced, examinations as prescribed shall be performed on the first five and on one additional casting for each additional five castings produced. If any of these additional castings proves to be unacceptable, each of the remaining four castings of that group shall be examined fully.

(b) All castings having maximum body thickness $4^1/_2$ in. (114 mm) and greater and castings of lesser thickness which are intended for severe service applications[65] shall be examined as follows:

(1) Each casting shall be subjected to 100% visual examination and to complete surface examination by either the magnetic particle or the liquid penetrant method. When the casting specification requires heat treatment, these examinations shall be conducted after that heat treatment. Acceptability limits for surface imperfections shall be as given in (a)(3) and (a)(4) above.

(2) All parts of castings up to 12 in. (300 mm) in thickness shall be subjected to radiographic examination and the radiographs compared to those given in ASTM E280, Standard Reference Radiographs for Heavy-Walled [$4^1/_2$-in. to 12-in. (114-mm to 305-mm)] Steel Castings. The maximum acceptable severity levels for imperfections shall be as follows:

Imperfection Category	Maximum Severity Level
A — Gas porosity	2
B — Sand and slag inclusions	2
C — Shrinkage	
Type 1	2
Type 2	2
Type 3	2
D — Cracks	0
E — Hot tears	0
F — Inserts	0

(3) For castings having a maximum thickness in excess of 12 in. (300 mm), all thicknesses which are less than 12 in. (300 mm) shall be examined radiographically in accordance with the preceding paragraph. All parts of such castings having thicknesses in excess of 12 in. (300 mm) shall be examined ultrasonically in accordance with Section V, Article 5. Any imperfections which do not produce indications exceeding 20% of the straight beam back reflection or do not reduce the height of the back reflection by more than 30% during a total movement of the transducer of 2 in. (50 mm) in any direction shall be considered acceptable. Imperfections exceeding these limits shall be repaired unless proved to be acceptable by other examination methods.

7-4 REPAIRS (25)

(a) Whenever an imperfection is repaired, the excavated areas shall be examined by the magnetic particle or liquid penetrant method to ensure it has been removed or reduced to an acceptable size.

(b) Whenever a surface imperfection is repaired by removing less than 5% of the intended thickness of metal at that location, welding need not be employed in making repairs. Where this is the case, the excavated area shall be blended into the surrounding surface so as to avoid any sharp contours.

(c) Castings of nonweldable materials which contain imperfections in excess of acceptable limits as given in 7-3 shall be rejected.

(d) For any type of defect, if the repair will entail removal of more than 75% of the thickness or a length in any direction of 6 in. (150 mm) or more, approval of the user or the user's designated agent responsible for purchasing the casting shall be obtained prior to making repairs.

(e) The finished surface of all repair welds shall be examined by the magnetic particle or liquid penetrant method. When subsequent heat treatment is required, this examination of the repaired area shall be conducted after heat treatment.

(f) See below.

(1) Except as provided in (2) and (3) below, all weld repairs shall be examined by radiography.

(2) Where the depth of repair is less than 1 in. or 20% of the section thickness, whichever is the lesser, and where the repaired section cannot be radiographed effectively, the first layer of each $^1/_4$ in. (6 mm) thickness of deposited weld metal shall be examined by the magnetic particle or the liquid penetrant method.

(3) Weld repairs which are made as a result of ultrasonic examination shall be reexamined by the same method when completed.

(g) When repair welding is done after the casting has been heat treated and when required by either the rules of this Section or the requirements of the casting specification, the repaired casting shall be postweld heat treated.

(h) All welding shall be performed using procedure qualifications in accordance with Section IX. The procedure qualification shall be performed on a test specimen of the same P-Number and same group as the production casting. The test specimen shall be subjected to the same heat treatment both before and after welding as will be applied to the production casting. All welders and operators performing this welding shall be qualified in accordance with Section IX.

7-5 IDENTIFICATION AND MARKING

Each casting shall be marked with the manufacturer's name and casting identification, including the applicable casting quality factor and material identification. The manufacturer shall furnish reports of the chemical and mechanical properties and certification that each casting conforms to all applicable requirements of this Appendix. The certification for castings for lethal service shall indicate the nature, location, and extent of any repairs.

MANDATORY APPENDIX 8
METHODS FOR LIQUID PENETRANT EXAMINATION (PT)

NOTE: Satisfactory application of this method of examination requires special skills in the techniques involved and in interpreting the results. The requirements specified herein presume application by suitably experienced personnel.

8-1 SCOPE

(a) This Appendix describes methods which shall be employed whenever liquid penetrant examination is specified in this Division.

(b) Section V, Article 6 shall be applied for detail requirements in methods and procedures, unless otherwise specified within this Appendix.

(c) Liquid penetrant examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

(d) Documentation showing that the required examinations have been performed and that the results are acceptable shall be made available to the Inspector.

(25) 8-2 CERTIFICATION OF COMPETENCY OF NONDESTRUCTIVE EXAMINATION PERSONNEL

The Manufacturer shall certify that each liquid penetrant examiner meets the following requirements.

(a) The examiner has vision, with correction if necessary, to enable the examiner to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 12 in. (300 mm), and is capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) The examiner is competent in the techniques of the liquid penetrant examination method for which the examiner is certified, including making the examination and interpreting and evaluating the results, except that, where the examination method consists of more than one operation, the examiner may be certified as being qualified only for one or more of these operations.

8-3 EVALUATION OF INDICATIONS

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant.

(a) A linear indication is one having a length greater than three times the width.

(b) A rounded indication is one of circular or elliptical shape with the length equal to or less than three times the width.

(c) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

8-4 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division.

All surfaces to be examined shall be free of:

(a) relevant linear indications;

(b) relevant rounded indications greater than $^3/_{16}$ in. (5 mm);

(c) four or more relevant rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less (edge to edge).

8-5 REPAIR REQUIREMENTS

Unacceptable imperfections shall be repaired and reexamination made to assure removal or reduction to an acceptable size. Whenever an imperfection is repaired by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after repair of an imperfection, the area shall be cleaned and welding performed in accordance with a qualified welding procedure.

(a) Treatment of Indications Believed Nonrelevant. Any indication which is believed to be nonrelevant shall be regarded as an imperfection unless it is shown by reexamination by the same method or by the use of other nondestructive methods and/or by surface conditioning that no unacceptable imperfection is present.

(b) Examination of Areas From Which Defects Have Been Removed. After a defect is thought to have been removed and prior to making weld repairs, the area shall be examined by suitable methods to ensure it has been removed or reduced to an acceptably sized imperfection.

(c) Reexamination of Repair Areas. After repairs have been made, the repaired area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners and reexamined by the liquid penetrant method and by all other methods of examination that were originally required for the affected area, except that, when the depth of repair is less than the radiographic sensitivity required, reradiography may be omitted.

MANDATORY APPENDIX 9 JACKETED VESSELS

(25)

Information formerly in this Appendix has been moved to Part UJV.

MANDATORY APPENDIX 10 QUALITY CONTROL SYSTEM

(25) 10-1 GENERAL

The Manufacturer or Assembler shall have and maintain a Quality Control System which will establish that all Code requirements,[4] including material, design, fabrication, examination (by the Manufacturer or Assembler), and for vessels and vessel parts, inspection (by the Authorized Inspector), will be met. The Quality Control Systems of Certificate Holders with a UM Designator shall include duties of a Certified Individual, as required by this Division. The Certified Individual authorized to provide oversight may also serve as the Certificate Holder's authorized representative responsible for signing data reports or certificates of conformance. Provided that Code requirements are suitably identified, the system may include provisions for satisfying any requirements by the Manufacturer, Assembler, or user which exceed minimum Code requirements and may include provisions for quality control of non-Code work. In such systems, the Manufacturer of vessels or vessel parts may make changes in parts of the system which do not affect the Code requirements without securing acceptance by the Inspector. [See UG-117(d).]

The system that the Manufacturer or Assembler uses to meet the requirements of this Division must be one suitable for the complexity of the work[66] performed and the size and complexity of the Manufacturer's organization.[67] A written description of the system the Manufacturer or Assembler will use to produce a Code item shall be available for review. Depending upon the circumstances, the description may be brief or voluminous.

The written description may contain information of a proprietary nature relating to the Manufacturer's or Assembler's processes. Therefore, the Code does not require any distribution of this information except for the Inspector, ASME designee, or an ASME Designated Organization as covered by 10-15(c). It is intended that information learned about the system in connection with the evaluation will be treated as confidential and that all loaned descriptions will be returned to the Manufacturer or Assembler upon completion of the evaluation.

10-2 OUTLINE OF FEATURES TO BE INCLUDED IN THE WRITTEN DESCRIPTION OF THE QUALITY CONTROL SYSTEM

The following is a guide to some of the features which should be covered in the written description of the Quality Control System and which is equally applicable to both shop and field work.

10-3 AUTHORITY AND RESPONSIBILITY

The authority and responsibility of those in charge of the Quality Control System shall be clearly established. Persons performing quality control functions shall have sufficient and well-defined responsibility, the authority, and the organizational freedom to identify quality control problems and to initiate, recommend and provide solutions.

10-4 ORGANIZATION

An organization chart showing the relationship between management and engineering, purchasing, manufacturing, construction, inspection, and quality control is required to reflect the actual organization. The purpose of this chart is to identify and associate the various organizational groups with the particular function for which they are responsible. The Code does not intend to encroach on the Manufacturer's right to establish, and from time to time to alter, whatever form of organization the Manufacturer considers appropriate for its Code work.

10-5 DRAWINGS, DESIGN CALCULATIONS, AND SPECIFICATION CONTROL (25)

(a) The Manufacturer's or Assembler's Quality Control System shall provide procedures that will ensure that the latest applicable drawings, design calculations, specifications, and instructions required by the Code, as well as authorized changes, are used for manufacture, examination, inspection, and testing.

(b) For Manufacturers or Assemblers of parts who do not perform or assume any design responsibility for the parts they manufacture, the Quality Control System need only describe how the design documents, including specifications, drawings, and sketches, that are received from

the purchaser of the part are controlled, and how the parts are controlled while in the custody of the parts Manufacturer or Assembler.

(c) The Manufacturer's or Assembler's Quality Control System shall provide procedures that will ensure that any computer program used for preparing calculations or conducting analysis meets the requirements of the Code. The procedures shall ensure that prepared calculations or analysis is verified as follows:

(1) The computer program calculations or analysis shall be verified to show that it produces correct solutions for the mathematical model within defined limits for each parameter of the model that is used.

(-a) A mathematical model may include mathematical equations, boundary conditions, initial conditions, and the geometry, physical, and material property data.

(-b) Verification is the process of determining if computational model accurately represents the underlying mathematical model and its solution.

(2) The mathematical model shall be verified to show that it produces correct solutions to the physical characteristics associated with the application.

NOTE: For (1) and (2), verification against examples found in ASME PTB-4, ASME Section VIII, Division 1 Example Problem Manual may be sufficient to show that verification is met.

In lieu of (1) and (2) above, the computer programs may be verified by the results confirmed by design analysis for each application.

(d) The Manufacturer's or Assembler's Quality Control System shall describe the requirements for establishing and documenting the qualifications of personnel performing design activities to the Code; (see Mandatory Appendix 47).

10-6 MATERIAL CONTROL

The Manufacturer or Assembler shall include a system of receiving control which will ensure that the material received is properly identified and has documentation including required Certificates of Compliance or Material Test Reports to satisfy Code requirements as ordered. The required Certificates of Compliance or Material Test Reports may be electronically transmitted from the material manufacturer or supplier to the Certificate Holder. The material control system shall ensure that only the intended material is used in Code construction.

10-7 EXAMINATION AND INSPECTION PROGRAM

The Manufacturer's or Assembler's Quality Control System shall describe the fabrication operations, including examinations, sufficiently to permit the Inspector, ASME designee, or an ASME Designated Organization to determine at what stages specific inspections are to be performed.

10-8 CORRECTION OF NONCONFORMITIES

There shall be a system agreed upon with the Inspector for correction of nonconformities. A nonconformity is any condition which does not comply with the applicable rules of this Division. Nonconformities must be corrected or eliminated in some way before the completed component can be considered to comply with this Division.

10-9 WELDING AND BRAZING (25)

The Quality Control System shall include provisions for indicating that welding/brazing conforms to requirements of Section IX as supplemented by this Division. Manufacturers intending to use AWS Standard Welding Procedures shall describe control measures used to assure that welding meets the requirements of this Division and Section IX.

10-10 NONDESTRUCTIVE EXAMINATION

The Quality Control System shall include provisions for identifying nondestructive examination procedures the Manufacturer or Assembler will apply to conform with the requirements of this Division.

10-11 HEAT TREATMENT (25)

The Quality Control System shall provide controls to insure that heat treatments as required by the rules of this Division are applied. Means shall be indicated by which the Inspector, ASME designee, or an ASME Designated Organization can verify that these Code heat treatment requirements are met. This may be by review of furnace time–temperature records or by other methods as appropriate.

10-12 CALIBRATION OF MEASUREMENT AND TEST EQUIPMENT

The Manufacturer or Assembler shall have a system for the calibration of examination, measuring, and test equipment used in fulfillment of requirements of this Division.

10-13 RECORDS RETENTION (25)

(a) The Manufacturer or Assembler shall have a system for the maintenance of radiograph review forms (see UW-51), Manufacturer's Data Reports (see UG-120), and Certificates of Compliance/Conformance (see UG-120) as required by this Division.

(b) The Manufacturer or Assembler shall maintain the documents outlined below for a period of at least 3 yr:

(1) Manufacturer's Partial Data Reports

(2) manufacturing drawings

(3) design calculations, including any applicable Proof Test Reports

(4) Material Test Reports and/or material certifications

(5) Pressure parts documentation and certifications

(6) Welding/Brazing Procedure Specifications and Procedure Qualification Records

(7) Performance Qualification Records for each welder, welding operator, brazer, and brazing operator who worked on the vessel or part

(8) NDE records and radiograph review forms

(9) repair procedure and records

(10) process control sheets

(11) heat treatment records and test results

(12) postweld heat treatment and postbraze heat treatment records

(13) nonconformances and dispositions

(14) pressure test records

(15) transfer forms [see UG-120(c)(1)(-e)]

(16) continuity records showing that the qualifications of welders, brazers, welding operators, and brazing operators have been maintained

(c) For Manufacturers of vessels bearing the UM Designator or vessels constructed under the provisions of UG-90.3(b) rules, the records listed in (b), for six representative vessels per year, shall be maintained as follows:

(1) vessels bearing the UM Designator for a period of 1 yr

(2) vessels constructed under the provisions of UG-90.3(b) rules for a period of 3 yr

10-14 SAMPLE FORMS

The forms used in the Quality Control System and any detailed procedures for their use shall be available for review. The written description shall make necessary references to these forms.

10-15 INSPECTION OF VESSELS AND VESSEL PARTS (25)

(a) Inspection of vessels and vessel parts shall be by the Inspector as defined in UG-91.

(b) The written description of the Quality Control System shall include reference to the Inspector.

(c) The Manufacturer shall make available to the Inspector, at the Manufacturer's plant or construction site, a current copy of the written description of the Quality Control System.

(d) The Manufacturer's Quality Control System shall provide for the Inspector at the Manufacturer's plant to have access to all drawings, calculations, specifications, procedures, process sheets, repair procedures, Proof Test Reports, records, test results, and any other documents as necessary for the Inspector to perform the required duties in accordance with this Division. The Manufacturer may provide the Inspector either access to or copies of such documents.

10-16 CERTIFICATIONS

(a) Methods other than written signature may be used for indicating certifications, authorizations, and approvals where allowed and as described elsewhere in this Division.

(b) Where other methods are employed, controls and safeguards shall be provided and described to ensure the integrity of the certification, authorization, and approval.

MANDATORY APPENDIX 12
ULTRASONIC EXAMINATION OF WELDS (UT)

12-1 SCOPE

(a) This Appendix describes methods which shall be employed when ultrasonic examination of welds is specified in this Division.

(b) Section V, Article 4 shall be applied for detail requirements in methods and procedures, unless otherwise specified in this Appendix.

(c) Ultrasonic examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

12-2 CERTIFICATION OF COMPETENCE OF NONDESTRUCTIVE EXAMINER

Personnel performing and evaluating ultrasonic examinations required by this Division shall meet the requirements of UW-54.

12-3 ACCEPTANCE–REJECTION STANDARDS

These Standards shall apply unless other standards are specified for specific applications within this Division.

Imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below.

(a) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

(b) Other imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths which exceed:

(1) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm);

(2) $^1/_3t$ for t from $^3/_4$ in. to $2^1/_4$ in. (19 mm to 57 mm);

(3) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm).

where t is the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

12-4 REPORT OF EXAMINATION

The Manufacturer shall prepare a report of the ultrasonic examination and a copy of this report shall be retained by the Manufacturer as required by this Division (see Mandatory Appendix 10, 10-13). The report shall contain the information required by Section V. In addition, a record of repaired areas shall be noted as well as the results of the reexamination of the repaired areas. The Manufacturer shall also maintain a record of all reflections from uncorrected areas having responses that exceed 50% of the reference level. This record shall locate each area, the response level, the dimensions, the depth below the surface, and the classification.

(25)

MANDATORY APPENDIX 13
VESSELS OF NONCIRCULAR CROSS SECTION

Information formerly in this Appendix has been moved to Part UNC.

MANDATORY APPENDIX 14 INTEGRAL FLAT HEADS WITH A LARGE, SINGLE, CIRCULAR, CENTRALLY LOCATED OPENING

(25)

14-1 SCOPE

(a) In accordance with UG-39(c)(1), flat heads which have a single, circular, centrally located opening that exceeds one-half of the head diameter shall be designed according to the rules which follow. The shell-to-flat head juncture shall be either integral, as shown in Figure UG-34, sketches (a), (b-1), (b-2), (d), and (g), or a butt weld, or a full penetration corner weld similar to the joints shown in Figure UW-13.2, sketches (a), (b), (c), (d), (e), and (f). When Figure UW-13.2, sketches (c) and (d) are used, the maximum wall thickness of the shell shall not exceed $^3/_8$ in. (10 mm) and the maximum design metal temperature shall not exceed 650°F (345°C). The central opening in the flat head may have a nozzle which is integral or integrally attached by a full penetration weld or may have an opening without an attached nozzle or hub. For openings in which the nozzle is attached with non-integral welds (i.e., a double fillet or partial penetration weld) use the design rules for an opening without an attached nozzle or hub.

(b) A general arrangement of an integral flat head with or without a nozzle attached at the central opening is shown in Division 2, Figure 4.6.1.

(c) The head thickness does not have to be calculated by UG-34 rules. The thickness which satisfies all the requirements of this Appendix meets the requirements of the Code.

14-2 NOMENCLATURE

Nomenclature is addressed in Division 2, 4.6.5.

14-3 DESIGN PROCEDURE

(a) The design procedure in Division 2, 4.6.4 shall be used for this Appendix.

(b) When this Appendix is applied for design, the applicable requirements of Division 2, 4.6.4 shall be used in accordance with UG-16(a) and Mandatory Appendix 46.

14-4 DATA REPORTS

When all the requirements of this Division and the supplemental requirements of this Appendix have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance with Mandatory Appendix 14, Integral Flat Heads with a Large, Single, Circular, Centrally Located Opening."

(25)

MANDATORY APPENDIX 17
DIMPLED OR EMBOSSED ASSEMBLIES

Information formerly in this Appendix has been moved to Part UDA.

MANDATORY APPENDIX 18
ADHESIVE ATTACHMENT OF NAMEPLATES

18-1 SCOPE

This Appendix covers the qualification of procedures for the adhesive attachment of nameplates. The use of adhesive systems for the attachment of nameplates is permitted only under the following conditions:

(a) The adhesive used is a pressure-sensitive acrylic adhesive that has been preapplied by the nameplate manufacturer to a nominal thickness of at least 0.005 in. (0.13 mm).

(b) The adhesive is protected with a moisture-stable liner.

(c) The vessel(s) to which the nameplate is being attached has a design temperature within the range of −40°F to 300°F (−40°C to 150°C), inclusive.

(d) The nameplate is applied to a clean, bare metal surface with attention being given to removal of anti-weld-spatter compound that may contain silicone.

(e) The nameplate application procedure is qualified as outlined in 18-2.

(f) The preapplied adhesive is used within 2 yr after initial adhesive application.

18-2 NAMEPLATE APPLICATION PROCEDURE QUALIFICATION

(a) The Manufacturer's Quality Control System [see U-2(h)] shall define that written procedures, acceptable to the Inspector, for the application of adhesive-backed nameplates shall be prepared and qualified.

(b) The application procedure qualification shall include the following essential variables, using the adhesive and nameplate manufacturers' recommendations where applicable:

(1) description of the pressure-sensitive acrylic adhesive system employed, including generic composition;

(2) the qualified temperature range [the cold box test temperature shall be −40°F (−40°C) for all applications];

(3) materials of nameplate and substrate when the mean coefficient of expansion at design temperature of one material is less than 85% of that for the other material;

(4) finish of the nameplate and substrate surfaces;

(5) the nominal thickness and modulus of elasticity at application temperature of the nameplate when nameplate preforming is employed. A change of more than 25% in the quantity [(nameplate nominal thickness)^2 × nameplate modulus of elasticity at application temperature] will require requalification.

(6) the qualified range of preformed nameplate and companion substrate contour combinations when preforming is employed;

(7) cleaning requirements for the substrate;

(8) application temperature range and application pressure technique;

(9) application steps and safeguards.

(c) Each procedure used for nameplate attachment by pressure-sensitive acrylic adhesive systems shall be qualified for outdoor exposure in accordance with Standard UL-969, Marking and Labeling Systems, with the following additional requirements:

(1) Width of nameplate test strip shall not be less than 1 in. (25 mm).

(2) Nameplates shall have an average adhesion of not less than 8 lb/in. (36 N/25 mm) of width after all exposure conditions, including low temperature.

(d) Any change in (b) above shall require requalification.

(e) Each lot or package of nameplates shall be identified with the adhesive application date.

(25)

MANDATORY APPENDIX 19
ELECTRICALLY HEATED OR GAS-FIRED JACKETED STEAM KETTLES

Information formerly in this Appendix has been moved to Part UJK.

MANDATORY APPENDIX 20
HUBS MACHINED FROM PLATE

20-1 SCOPE

This Appendix covers the requirements for hubs of tubesheets, lap joint stub ends, and flat heads machined from plate when the hub length is in the through thickness direction of the plate.

20-2 MATERIAL

Plate shall be manufactured by a process that produces material having through thickness properties which are at least equal to those specified in the material specification. Such plate can be, but is not limited to, that produced by methods such as electroslag (ESR) and vacuum arc remelt (VAR). The plate must be tested and examined in accordance with the requirements of the material specification and the additional requirements specified in the following paragraphs:

Test specimens, in addition to those required by the material specifications, shall be taken in a direction parallel to the axis of the hub and as close to the hub as practical, as shown in Figure UW-13.3. At least two tensile test specimens shall be taken from the plate in the proximity of the hub with one specimen taken from the center third of the plate width as rolled, and the second specimen taken at 90 deg around the circumference from the other specimen. Both specimens shall meet the mechanical property requirements of the material specification. All dimensional requirements of Figure UW-13.3 shall apply.

Subsize test specimens conforming to the requirements of Figure 4 of SA-370 may be used if necessary, in which case the value for "elongation in 2 in. (50 mm)," required by the material specification, shall apply to the gage length specified in Figure 4.

For carbon and low alloy steels, the reduction-of-area shall not be less than 30%; for those materials for which the material specification requires a reduction-of-area value greater than 30%, the higher value shall be met.

20-3 EXAMINATION REQUIREMENTS

Each part shall be examined as follows:

(a) Before and after machining, the part, regardless of thickness, shall be ultrasonically examined by the straight beam technique in accordance with SA-388. The examination shall be in two directions approximately at right angles, that is, from the cylindrical or flat rectangular surfaces of the hub and in the axial direction of the hub.

The part shall be unacceptable:

(1) if the examination results show one or more indications accompanied by loss of back reflection larger than 60% of the reference back reflection;

(2) if the examination results show indications larger than 40% of the reference back reflection when accompanied by a 40% loss of back reflection.

(b) Before welding the hub of the tubesheet or flat head to the adjacent shell, the hub shall be examined by magnetic particle or liquid penetrant methods in accordance with Mandatory Appendix 6 or Mandatory Appendix 8.

(c) After welding, the weld and the area of the hub for at least $1/2$ in. (13 mm) from the edge of the weld shall be 100% radiographed in accordance with UW-51. As an alternative, the weld and hub area adjacent to the weld may be ultrasonically examined in accordance with Mandatory Appendix 12.

20-4 DATA REPORTS

When all the requirements of this Division and the supplemental requirements of this Appendix have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance with Mandatory Appendix 20, Hubs Machined From Plate."

MANDATORY APPENDIX 21 JACKETED VESSELS CONSTRUCTED OF WORK-HARDENED NICKEL

21-1 SCOPE

Jacketed vessels having an inner shell constructed of nickel sheet or plate that meets the requirements of SB-162 and that has been work-hardened by a planishing operation over its entire surface during fabrication, with a corresponding increase in strength against collapse, shall meet the requirements of this Division, provided that the additional provisions which follow are met.

21-2 DESIGN REQUIREMENTS

(a) The maximum size of any vessel shall be 8 ft (2.4 m) I.D.

(b) The maximum operating temperature shall not exceed 400°F (205°C).

(c) Any cylindrical skirt (flange) on a hemispherical head that is subject to external pressure shall be designed as a cylinder.

(d) The thickness of the inner shell of each vessel shall be such as to withstand without failure a hydrostatic test pressure in the jacket space of not less than three times the desired maximum allowable working pressure.

(e) In no case shall the thickness of the inner shell or head be less than that determined from the external pressure chart in Section II, Part D, Subpart 3, Figure NFA-4.

(f) The required moment of inertia of stiffening rings shall be determined from the appropriate chart in Section II, Part D, Subpart 3 for the material used for the rings.

(g) The outer shell and head shall be designed for increased strength, if necessary, to accommodate the test pressure specified in (d) above, in order to avoid rejection of the vessel under UG-99(d).

21-3 FABRICATION

Any butt weld that is subject to the external pressure shall be ground flush with the base metal, and the deposited weld metal and the heat-affected zone shall be work-hardened in the same manner as the base metal.

21-4 DATA REPORTS

When all the requirements of this Division and the supplemental requirements of this Appendix have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance with Mandatory Appendix 21, Jacketed Vessels Constructed of Work-Hardened Nickel."

MANDATORY APPENDIX 22 INTEGRALLY FORGED VESSELS

(25)

Information formerly in this Appendix has been moved to Part UIF.

MANDATORY APPENDIX 23
EXTERNAL PRESSURE DESIGN OF COPPER, COPPER ALLOY, AND TITANIUM ALLOY CONDENSER AND HEAT EXCHANGER TUBES WITH INTEGRAL FINS

23-1 SCOPE

The rules in this Appendix cover the proof test procedure and criteria for determining the maximum allowable external working pressure of copper, copper alloy, and titanium alloy condenser and heat exchanger tubes with helical fins that are integrally extended from the tube wall as an alternative to the requirements of UG-8(b)(4). This Appendix may only be used when the specified corrosion allowance for the tubes is zero. In addition, when using SB-543, this Appendix may only be used when the finning operations are performed after the tubes have been welded, tested, and inspected according to SB-543.

23-2 MATERIALS

(a) Copper and copper alloy tubes shall meet SB-359, SB-543, or SB-956.

(b) Titanium alloy tubes shall meet SB-338.

23-3 TEST PROCEDURE

(a) Test three full size specimens to failure (visible collapse) by external hydrostatic pressure.

(b) The maximum allowable working pressure P shall be determined by

$$P = F\left(\frac{B}{3}\right)\left(\frac{Y_s}{Y_a}\right)$$

where

B = minimum collapse pressure, psi (kPa)

F = factor to adjust for change in strength due to design temperature
= S/S_2

S = maximum allowable stress value for the tube material at design temperature, as given in the tables referenced in UG-23 but not to exceed S_2, psi

S_2 = maximum allowable stress value for the tube material at test temperature, as given in the tables referenced in UG-23, psi

Y_a = actual average yield strength determined from the unfinned length of the three specimens tested at room temperature, psi (kPa)

Y_s = specified minimum yield strength at room temperature, psi (kPa)

23-4 CRITERIA (25)

(a) The design of copper and copper alloy finned tubes to this Appendix shall meet the following requirements:

(1) Design temperature shall be limited to the maximum temperature listed in Section II, Part D, Subpart 1, Table 1B corresponding to the time independent allowable stress, or the maximum temperature shown on the external pressure chart for the corresponding material, whichever is less.

(2) Tubes shall have external and/or internal integrally extended helical fins and the sum of external plus internal fins shall be at least 10 fins/in. (10 fins/25 mm).

(3) Dimensions and permissible variations shall be as specified in SB-359 or SB-956.

(b) The design of titanium alloy finned tubes to this Appendix shall meet the following requirements:

(1) Design temperature shall not exceed 600°F (315°C).

(2) Tubes shall have external integrally extended helical fins only and shall have at least 10 fins/in. (10 fins/25 mm).

(3) Dimensions and permissible variations shall be as specified in SB-359 (Specification for Copper and Copper-Alloy Seamless Condenser and Heat Exchanger Tubes With Integral Fins).

(c) Additional requirements for copper, copper alloy, and titanium alloy tubes designed to this Appendix are as follows:

(1) Test specimens shall be identical in fin geometry and pitch to production tubes.

(2) Test specimens of 50 outside diameters or more in length shall qualify all totally finned lengths.

(3) Unfinned length at the ends or at an intermediate section shall qualify that length and all lesser unfinned lengths.

(4) Nominal wall thickness under the fin and at the unfinned area shall qualify all thicker wall sections but with no increase in P.

(5) Outside diameter of the finned section shall not exceed the outside diameter of the unfinned section.

(6) Tests shall be done in accordance with 23-3, witnessed by and subjected to the acceptance of the Inspector.

23-5 DATA REPORTS

When all the requirements of this Division and the supplemental requirements of this Appendix have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance with Mandatory Appendix 23, External Pressure Design of Copper, Copper Alloy, and Titanium Alloy Condenser and Heat Exchanger Tubes With Integral Fins."

(25)

MANDATORY APPENDIX 24
DESIGN RULES FOR CLAMP CONNECTIONS

Information formerly in this Appendix has been moved to Part UCC.

MANDATORY APPENDIX 26 BELLOWS EXPANSION JOINTS

(25)

Information formerly in this Appendix has been moved to Part UEB.

(25)

MANDATORY APPENDIX 27
ALTERNATIVE REQUIREMENTS FOR GLASS-LINED VESSELS

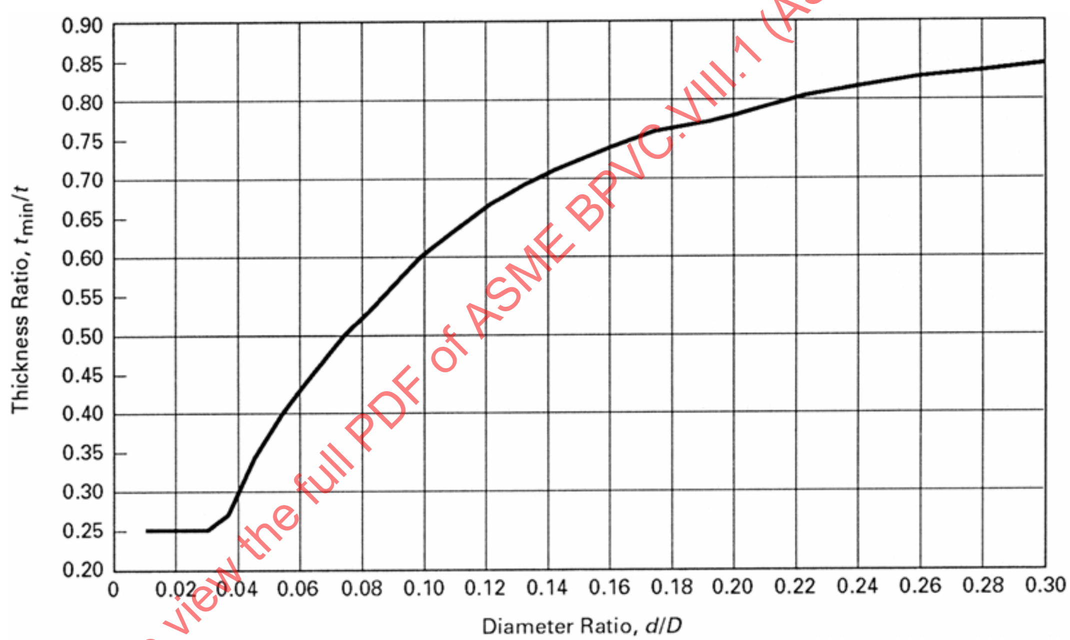
Information formerly in this Appendix has been moved to Part UGL.

MANDATORY APPENDIX 30
RULES FOR DRILLED HOLES NOT PENETRATING THROUGH VESSEL WALL

30-1 SCOPE

Partially drilled radial holes in cylindrical and spherical shells may be used, provided they are 2.0 in. (50 mm) or less in diameter and the shell diameter to thickness ratio $D/t \geq 10$. The acceptance criterion for the depth of the hole is the plot of the ratio t_{min}/t versus d/D that is on or above the curve in Figure 30-1.

Figure 30-1
Thickness Ratio Versus Diameter Ratio



30-2 SUPPLEMENTARY REQUIREMENTS

In addition, the following conditions shall be met:

(a) The minimum remaining wall thickness t_{min} shall not be less than 0.25 in. (6 mm).

(b) The calculated average shear stress, $\tau = Pd/4t_{min}$, in the remaining wall shall not exceed 0.8S.

(1) Unless the provisions of U-2(g) are satisfied, the centerline distance between any two such drilled holes or between a partially drilled hole and an unreinforced opening shall satisfy the requirements of UG-36(c)(3)(-c) and UG-36(c)(3)(-d).

(2) Unless the provisions of U-2(g) are satisfied, partially drilled holes shall not be placed within the limits of reinforcement of a reinforced opening.

(c) The outside edge of the hole shall be chamfered; for flat bottom holes, the inside bottom corner of the hole shall have a minimum radius of the lesser of $^1/_4$ in. (6 mm) or $d/4$.

(d) These rules are not applicable to studded connections (see UG-43) and telltale holes (see UG-25).

30-3 NOMENCLATURE

Symbols used in this Appendix are as follows:

D = vessel inside diameter
d = diameter of drilled hole
P = design pressure (see UG-21)
S = maximum allowable stress value
t = nominal thickness in corroded condition
t_{min} = remaining wall thickness

MANDATORY APPENDIX 31
RULES FOR CR–MO STEELS WITH ADDITIONAL REQUIREMENTS FOR WELDING AND HEAT TREATMENT

31-1 SCOPE

This Appendix covers special fabrication and testing rules for a group of materials for which tightly controlled welding and heat treatment procedures are of particular importance. The materials and appropriate specifications covered by this Appendix are listed in Table 31-1.

The requirements of this Appendix are in addition to the rules in other parts of this Division for carbon and low alloy steels. In cases of conflicts, the rules in this Appendix shall govern.

This Appendix number shall be shown on the Manufacturer's Data Report Form.

31-2 POSTWELD HEAT TREATMENT

(a) 2$^1/_4$Cr–1Mo–$^1/_4$V, 3Cr–1Mo–$^1/_4$V–Ti–B, and 3Cr–1Mo–$^1/_4$V–Cb–Ca Materials. The final postweld heat treatment shall be in accordance with the requirements of this Division for P-No. 5C materials.

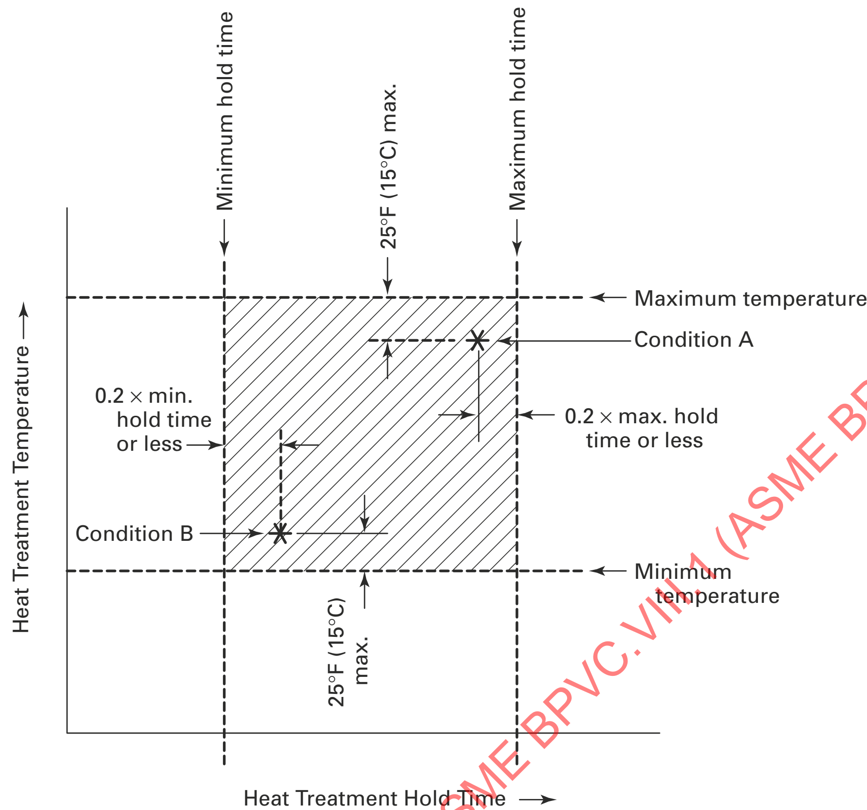
(b) 2$^1/_4$Cr–1Mo Materials. The final postweld heat treatment temperature shall be in accordance with the requirement of this Division for P-No. 5A materials except that the permissible minimum normal holding temperature is 1,200°F (650°C), and the holding time shall be 1 hr/in. up to a nominal thickness of 5 in. (125 mm). For thicknesses over 5 in. (125 mm), the holding time shall be 5 hr plus 15 min for each additional inch over 5 in. (125 mm).

Table 31-1
Material Specifications (25)

Nominal Composition	Type/ Grade	Specification No.	Product Form
2$^1/_4$Cr–1Mo	Grade 22, Cl. 3	SA-508	Forgings
	Grade 22, Cl. 3	SA-541	Forgings
	Type B, Cl. 4	SA-542	Plates
	Grade 8, Cl. A	SA-487	Castings
2$^1/_4$Cr–1Mo–$^1/_4$V	Grade F22V	SA-182	Forgings
	Grade F22V	SA-336	Forgings
	Grade 22V	SA-541	Forgings
	Type D, Cl. 4a	SA-542	Plates
	Grade 22V	SA-832	Plates
3Cr–1Mo–$^1/_4$V–Ti–B	Grade F3V	SA-182	Forgings
	Grade F3V	SA-336	Forgings
	Grade 3V	SA-508	Forgings
	Grade 3V	SA-541	Forgings
	Type C, Cl. 4a	SA-542	Plates
	Grade 21V	SA-832	Plates
3Cr–1Mo–$^1/_4$V–Cb–Ca	Grade F3VCb	SA-182	Forgings
	Grade F3VCb	SA-336	Forgings
	Grade 3VCb	SA-508	Forgings
	Grade 3VCb	SA-541	Forgings
	Type E, Cl. 4a	SA-542	Plates
	Grade 23V	SA-832	Plates

GENERAL NOTE: The materials in this table have a specified minimum tensile strength of 85 ksi (585 MPa) or greater.

Figure 31-1



31-3 TEST SPECIMEN HEAT TREATMENT

(a) In fulfilling the requirements of UCS-85(a), two sets of tension specimens and one set of Charpy impact specimens shall be tested. One set each of the tension specimens shall be exposed to heat treatment Condition A. The second set of tension specimens and the set of Charpy impact specimens shall be exposed to heat treatment Condition B.

Condition A: Temperature shall be no lower than the actual maximum vessel-portion temperature, less 25°F (15°C). Time at temperature shall be no less than 80% of the actual hold time of the vessel-portion exposed to the maximum vessel-portion temperature.

Condition B: Temperature shall be no higher than the actual minimum vessel-portion temperature, plus 25°F (15°C). Time at temperature shall be no more than 120% of the actual hold time of the vessel-portion exposed to the minimum vessel-portion temperature.

(b) Suggested procedure for establishing test specimen heat treatment parameters:

(1) Establish maximum and minimum temperatures and hold times for the vessel/component heat treatment based on experience/equipment.

(2) Determine Conditions A and B for the test specimen heat treatments.

Table 31-2
Composition Requirements for 2¼Cr–1Mo–¼V Weld Metal

Welding Process	C	Mn	Si	Cr	Mo	P	S	V	Cb
SAW	0.05–0.15	0.50–1.30	0.05–0.35	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040
SMAW	0.05–0.15	0.50–1.30	0.20–0.50	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040
GTAW	0.05–0.15	0.30–1.10	0.05–0.35	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040
GMAW	0.05–0.15	0.30–1.10	0.20–0.50	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040

(3) Vessel heat treatment temperature and hold time limitations and test specimen Conditions A and B are shown in Figure 31-1 (shaded area).

31-4 WELDING PROCEDURE QUALIFICATION AND WELDING CONSUMABLES TESTING

(a) Welding procedure qualifications using welding consumables of the same classification or trade designation as those to be used in production shall be made for material welded to itself or to other materials. The qualifications shall conform to the requirements of Section IX, and the maximum tensile strength at room temperature shall be 110 ksi (760 MPa) (for heat treatment Conditions A and B).

(b) Weld metal from each heat or lot of electrodes and filler-wire–flux combination shall be tested, unless specific heat- or lot-traceable test reports meeting the additional requirements of this Appendix related to welding consumables testing have been provided by the welding consumables manufacturer. The minimum and maximum tensile properties shall be met in PWHT Conditions A and B. The minimum CVN impact properties shall be met in PWHT Condition B. Testing shall be in general conformance with SFA-5.5 for covered electrodes and SFA-5.23 for filler-wire–flux combinations.

(c) Duplicate testing in the PWHT Condition A and PWHT Condition B (see 31-3) is required. The minimum tensiles and CVN impact properties for the base material shall be met. CVN impact testing is only required for Condition B.

For $2^1/_4$Cr–1Mo–$^1/_4$V material, the weld metal shall meet the composition requirements listed in Table 31-2. For all other materials, the minimum carbon content of the weld metal shall be 0.05%.

31-5 TOUGHNESS REQUIREMENTS

The minimum toughness requirements for base metal, weld metal, and heat-affected zone, after exposure to the simulated postweld heat treatment Condition B, shall be as follows:

Number of Specimens	Impact Energy, ft-lb
Average of 3	40
Only one in set	35 min.

GENERAL NOTE: Full size Charpy V-notch, transverse, tested at the MDMT.

If the material specification or other parts of this Division have more demanding toughness requirements, they shall be met.

MANDATORY APPENDIX 32
LOCAL THIN AREAS IN CYLINDRICAL SHELLS AND IN SPHERICAL SEGMENTS OF SHELLS

32-1 SCOPE

The rules of this Appendix permit acceptable local thin areas (LTAs) in cylindrical shells or spherical segments of shells (such as spherical vessel, hemispherical heads, and the spherical portion of torispherical and ellipsoidal heads) under internal pressure be less than the required thickness required by UG-16, UG-27, or UG-32 as applicable. Local thin areas on the inside or outside of cylindrical shells or spherical segments of shells designed for internal pressure are acceptable, provided they meet the requirements in this Appendix.

32-2 GENERAL REQUIREMENTS

(a) The Manufacturer shall maintain records of the calculations and the location and extent of all LTAs that are evaluated using this Appendix, and provide such information to the purchaser or the User or the User's designated agent if requested. This information shall be documented in the design calculations made to meet the requirements of this Appendix.

(b) The maximum design temperature shall not exceed the maximum temperature limits specified in Mandatory Appendix 1, Table 1-4.3.

(c) This Appendix shall not be applied to Part UF vessels.

(d) The provisions of this Appendix do not apply to corrosion-resistant linings or overlays.

(e) All other applicable requirements of this Division shall be met.

32-3 NOMENCLATURE

C = projected circumferential length of LTA in a cylindrical shell, in.

D = per UG-32

D_L = maximum dimension of LTA in a spherical segment, in.

L = projected axial length of LTA in a cylindrical shell, in.

LTA = local thin area

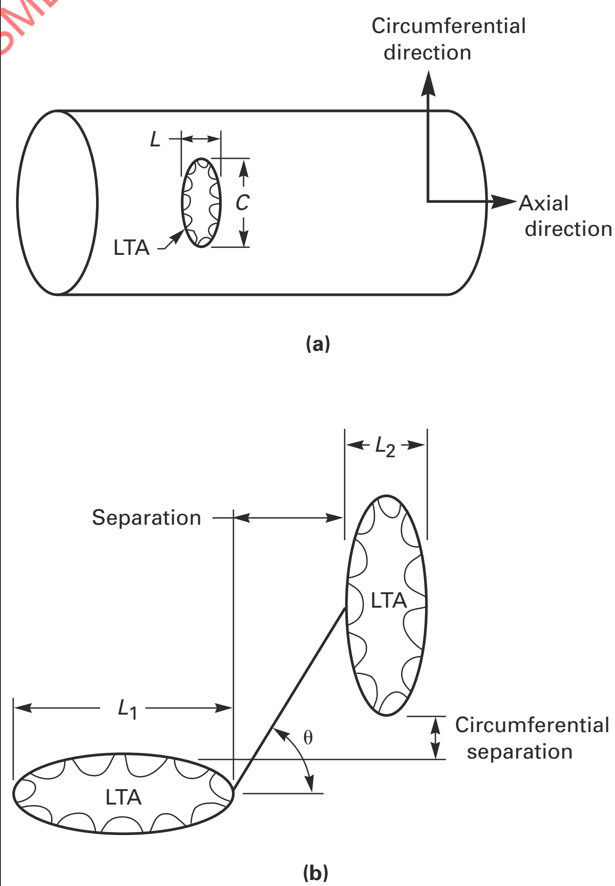
R = inside radius for cylindrical shell or spherical segment; for ellipsoidal heads $R = K_o D$ where K_o is from Table UG-33.1, in.

t = required thickness per UG-27(c), UG-27(d), UG-32(c), UG-32(d), or UG-32(e), as applicable, but not less than thickness requirements of UG-16, in.

t_L = minimum thickness of LTA, in.

θ = see Figure 32-3

Figure 32-3
Nomenclature



32-4 ALLOWABLE LOCATIONS FOR LOCAL THIN AREAS

(a) For openings meeting UG-36(c)(3), the minimum distance between the edge of the LTA and the center of the opening shall be equal to or greater than the inside diameter of the opening plus $\sqrt{Rt}$.

(b) For openings not meeting UG-36(c)(3), the minimum distance between the edge of the LTA and the reinforcement limit of the opening shall be equal to or greater than $\sqrt{Rt}$.

(c) For torispherical and ellipsoidal heads, the edge of an LTA shall not be closer than $2.5\sqrt{Rt}$ to the cylindrical shell side of the tangent line of the head-to-cylinder junction.

(d) An LTA is not acceptable within the torus portion of a torispherical head or an ellipsoidal head.

(e) The LTA for a torispherical head must lie entirely within the spherical portion of the head. See Figure 32-4-1.

(f) The LTA for an ellipsoidal head must lie entirely within a circle, the center of which coincides with the axis of the vessel, and the diameter of which is equal to 80% of the shell inside diameter. See Figure 32-4-2.

(g) A constant-thickness head-to-cylinder junction for a hemispherical head is not considered an area of high stress for LTA rules. The LTA for a hemispherical head is acceptable within the entire head and shell region for a constant-thickness hemispherical head-to-cylinder junction as shown in Figure 32-4-3, sketch (a). The location for an LTA is limited for a nonconstant-thickness hemispherical head-to-cylinder junction as shown in Figure 32-4-3, sketch (b). For both constant-thickness and nonconstant-thickness hemispherical head-to-cylinder junctions, LTAs are limited by (a), (b), and (h).

(h) The edge of an LTA shall not be closer than $2.5\sqrt{Rt}$ to the centerline of a stiffing ring or structural support.

(i) A junction between two sections of the same thickness within a cylindrical shell, hemispherical head, torispherical head, or ellipsoidal head is not considered an area of high stress for LTA rules and does not limit the allowable location of an LTA.

(j) An LTA is not acceptable within a flat head or a conical head.

Figure 32-4-1
Limits for Torispherical Head

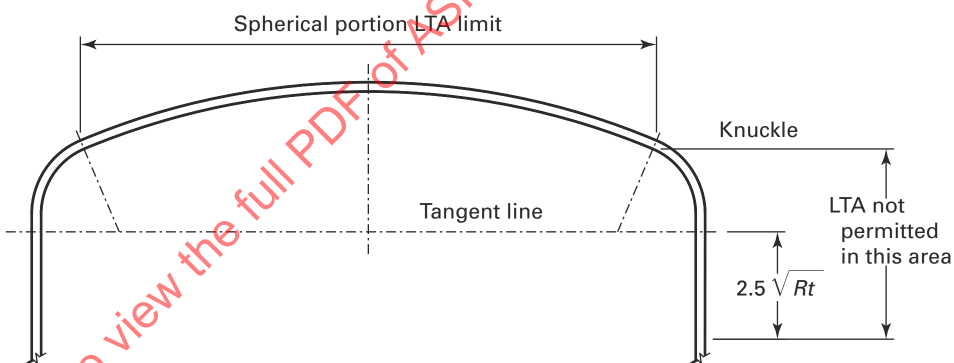


Figure 32-4-2
Limits for Ellipsoidal Head

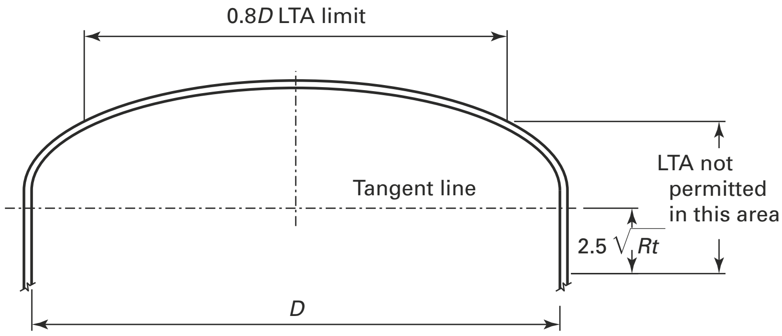
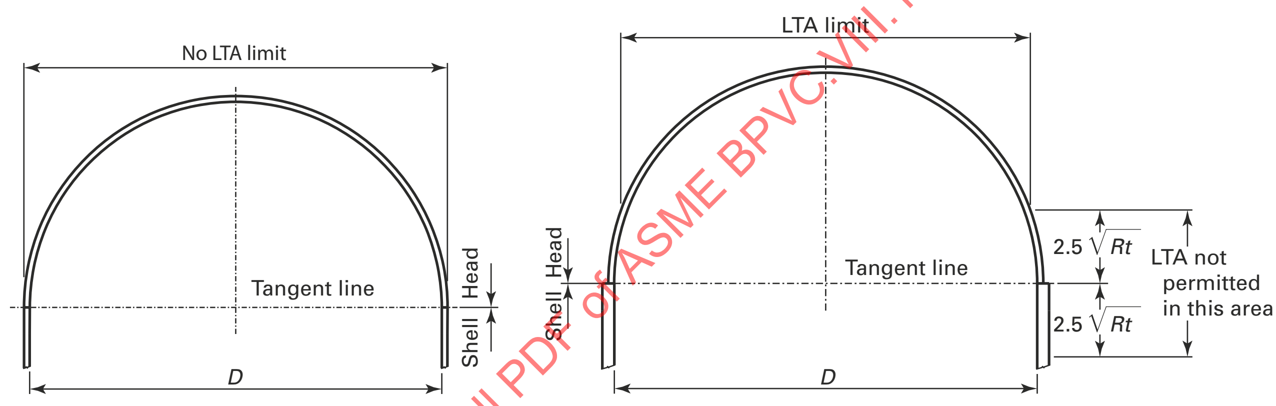


Figure 32-4-3
Limits for Hemispherical Head



(a) Constant Thickness Junction (b) Nonconstant Thickness Junction

32-5 BLEND GRINDING REQUIREMENTS FOR LOCAL THIN AREAS

(a) The blend between the LTA and the thicker surface shall be with a taper length not less than 3 times the LTA depth as shown in Figure 32-5-1.

(b) The minimum bottom blend radius shall be equal to or greater than 2 times the LTA depth as shown in Figure 32-5-1.

32-6 SINGLE LOCAL THIN AREAS IN CYLINDRICAL SHELLS

(a) Single LTA shall satisfy the following equations:

$$\frac{t_L}{t} \geq 0.9 \quad (1)$$

$$L \leq \sqrt{Rt} \quad (2)$$

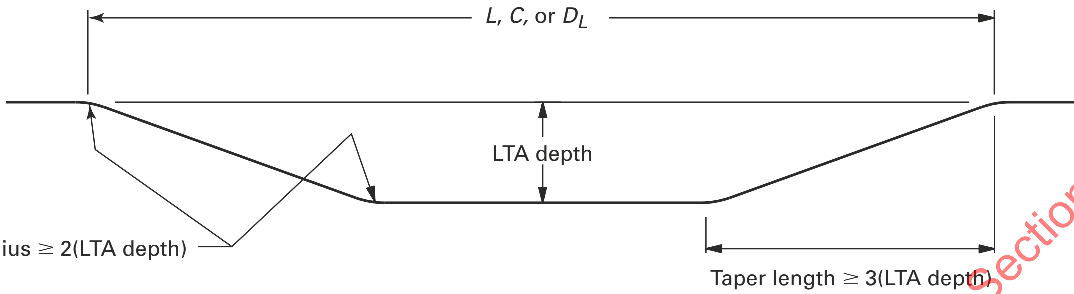
$$C \leq 2\sqrt{Rt} \quad (3)$$

$$t - t_L \leq \frac{3}{16}\text{ in.} \quad (4)$$

(b) The longitudinal stresses on the LTA from mechanical loads other than internal pressure shall not exceed 0.3S.

(c) The thickness at the LTA shall meet the requirements of UG-23(b) and/or UG-28 as applicable.

Figure 32-5-1
LTA Blend Grinding



32-7 MULTIPLE LOCAL THIN AREAS IN CYLINDRICAL SHELLS

(a) A pair of local areas with finished axial length, L_1 and L_2 [see Figure 32-3, sketch (b)] are acceptable if the individual LTA satisfies the requirements of 32-6 above and one of the following conditions [(1) or (2)] is met.

(1) When $\theta \le 45$ deg, the minimum axial separation [see Figure 32-3, sketch (b)] shall be the greater of:

$$\frac{(1.0 + 1.5\cos\theta)(L_1 + L_2)}{2} \text{ or } 2t$$

(2) When $\theta > 45$ deg, both of the following shall be met:

(-a) The minimum axial separation shall be equal to or greater than:

$$\frac{2.91\cos\theta\,(L_1 + L_2)}{2}$$

(-b) The minimum circumferential separation shall be equal to or greater than $2t$.

(b) Multiple pairs of LTA are acceptable, provided all pairs meet the rules of a single pair specified in (a).

(c) Multiple local thin areas may be combined as a single LTA. The resultant single LTA is acceptable if it satisfies the rules of 32-6.

32-8 SINGLE LOCAL THIN AREAS IN SPHERICAL SEGMENTS OF SHELLS

(a) The single LTA shall satisfy the following equations:

$$\frac{t_L}{t} \ge 0.9 \tag{5}$$

$$D_L \le \sqrt{Rt} \tag{6}$$

$$t - t_L \le \frac{3}{16}\text{ in.} \tag{7}$$

(b) The thickness at the LTA shall meet the requirements of UG-28(d) or UG-33 as applicable.

32-9 MULTIPLE LOCAL THIN AREAS IN SPHERICAL SEGMENTS OF SHELLS

(a) Multiple LTAs may be combined and evaluated as a single LTA. The encompassed areas of the combined LTAs shall be within the D_L dimension.

(b) Each LTA in the encompassed area shall meet the rules of 32-8.

(c) Multiple LTAs may be treated as single LTAs provided their edges are no closer than $2.5\sqrt{Rt}$.

32-10 DATA REPORTS

When all the requirements of this Division and supplemental requirements of this Appendix have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance With Mandatory Appendix 32, Local Thin Areas in Cylindrical Shells and in Spherical Segments of Shells."

MANDATORY APPENDIX 34
REQUIREMENTS FOR USE OF HIGH SILICON STAINLESS STEELS FOR PRESSURE VESSELS

34-1 SCOPE

(a) This Appendix covers rules for the use of high silicon stainless steel materials. The materials and appropriate specifications covered by this Appendix are listed in Table 34-1. High silicon materials are those stainless steel materials with silicon in the range of 3.7% to 6.0%.

(b) The requirements of this Appendix are in addition to the rules in other parts of this Division on high alloy steels. In cases of conflict, the rules of this Appendix shall govern.

(c) This Appendix number shall be shown on the Manufacturer's Data Report.

34-2 HEAT TREATMENT

(a) 17.5Cr–17.5Ni–5.3Si and 18Cr–15Ni–4Si

(1) Materials shall be solution annealed at a temperature of 2,010°F to 2,140°F (1 100°C to 1 170°C), followed by rapid cooling.

(2) Heat treatment after forming is neither required nor prohibited. If heat treatment is used, it shall be performed at a temperature of 2,010°F to 2,140°F (1 100°C to 1 170°C), followed by rapid cooling.

(b) 14Cr–16Ni–6Si–Cu–Mo

(1) Materials shall be solution annealed at a temperature of 1,950°F (1 065°C) minimum, followed by rapid cooling.

(2) Heat treatment after forming is neither required nor prohibited. If heat treatment is used, it shall be performed at a temperature of 1,950°F (1 065°C) minimum, followed by rapid cooling.

34-3 WELD PROCEDURE QUALIFICATION

(a) Welding procedure qualifications using production-weld consumable shall be made for material welded to itself or to other materials. The qualifications shall conform to Section IX and additional requirements in Table 34-2.

(b) Welding of 18Cr–20Ni–5.5Si and 14Cr–16Ni–6Si–Cu–Mo materials is limited to the GTAW and GMAW processes.

(c) Welding of 17.5Cr–17.5Ni–5.3Si and 18Cr–15Ni–4Si materials is limited to GMAW, GTAW, SMAW, and PAW.

Table 34-1
Material Specifications

Nominal Composition	UNS	Specification	Product Form
14Cr–16Ni–6Si–Cu–Mo	S38815	SA-213	Seamless tubing
		SA-240	Plate, sheet, and strip
		SA-249	Welded tubing
		SA-312	Seamless and welded pipe
		SA-403	Seamless and welded fittings
		SA-479	Bars and shapes
17.5Cr–17.5Ni–5.3Si	S30601	SA-240	Plate, sheet, and strip
18Cr–15Ni–4Si	S30600	SA-479	Bars and shapes
		SA-182	Forged flanges and fittings
		SA-240	Plate, sheet, and strip
		SA-312	Seamless and welded pipe
18Cr–20Ni–5.5Si	S32615	SA-479	Bars and shapes
		SA-240	Plate, sheet, and strip
		SA-213	Seamless tubing
		SA-312	Seamless and welded pipe

Table 34-2
Additional Requirements

Nominal Composition	UNS	Requirements
14Cr–16Ni–6Si–Cu–Mo	S38815	Separate welding procedure and performance qualifications shall be conducted in accordance with Section IX.
17.5Cr–17.5Ni–5.3Si	S30601	Maximum thickness of the material at the welds shall not exceed 1 in. (25 mm). Dimension "A" for the bend test jig in Section IX, Figure QW-466.1 shall be 4t [1$\frac{1}{2}$ in. (38 mm) for $\frac{3}{8}$ in. (10 mm) thick specimen].
18Cr–15Ni–4Si	S30600	Plate material shall not exceed 2 in. (50 mm) and bars and tube material shall not exceed 4 in. (100 mm) dia. Dimension "A" for the bend test jig in Section IX, Figure QW-466.1 shall be 4t [1$\frac{1}{2}$ in. (38 mm) for $\frac{3}{8}$ in. (10 mm) thick specimen].
18Cr–20Ni–5.5Si	S32615	Grain size of the material, determined in accordance with ASTM Methods E112, Plate II, shall be No. 3 or finer. The maximum nominal thickness of the weld shall be limited to $\frac{1}{2}$ in. (13 mm).

34-4 TOUGHNESS REQUIREMENTS

Minimum design metal temperature for the materials in this Appendix shall be limited to −50°F (−46°C) and warmer.

34-5 ADDITIONAL REQUIREMENTS

(a) The rules of Part UHA for austenitic stainless steels shall apply.

(b) The additional requirements shown in Table 34-2 shall apply to these materials.